1 MEASUREMENTS AND EXPERIMENTATION

Syllabus :

(i) *International system of units (the required S.I. units with correct symbols are given at the end of this syllabus). Other commonly used system of units – FPS and CGS.*

(ii) *Measurements using common instruments, Vernier callipers and micrometre screw gauge for length and simple pendulum for time.*

Scope – Measurement of length using vernier callipers and micrometre screw gauge. Decreasing least count leads to an increase in accuracy; least count (L.C.) of vernier callipers and screw gauge, zero error (basic idea) (no numerical problems on callipers and screw gauge). Simple pendulum; time period, frequency, graph of length l vs. T^2 only; slope of the graph. Formula $T = 2\pi\sqrt{l/g}$ (No derivation). Only simple numerical problems.

(A) SYSTEMS OF UNIT AND UNITS IN S.I. SYSTEM

1.1 NEED OF UNIT FOR MEASUREMENT

Physics, like other branches of science require experimental studies which involve measurements. For the measurement of a physical quantity, we consider a constant quantity of same nature as a standard and then we compare the given quantity with the standard quantity *i.e.* we find the number which expresses, how many times the *standard* quantity is contained in the given physical quantity. Thus

Measurement is the process of comparison of the given physical quantity with the known standard quantity of the same nature.

The standard quantity used to measure the given physical quantity is called the ***unit***. For quantities of different nature, we use different units.

Unit is the quantity of a constant magnitude which is used to measure the magnitudes of other quantities of the same nature.

The result of measurement of a physical quantity is expressed in terms of the following *two* parameters :

(i) The ***unit*** in which the quantity is being measured, and

(ii) The ***numerical value*** which expresses, how many times the above selected unit is contained in the given quantity.

Thus the magnitude of a physical quantity is expressed as :

Physical quantity = (numerical value) × (unit)

Examples : (i) If the length of a piece of cloth is 10 metre, it means that the length is measured in the unit metre and this unit is contained 10 times in the length of that piece of cloth.

(ii) If the mass of a given quantity of sugar is 5 kilogram, it means that the mass is measured in the unit kilogram and this unit is contained 5 times in the given quantity of sugar.

Choice of unit

To measure a physical quantity, the unit chosen should have the following properties :

(i) The unit should be of *convenient size*.

(ii) It should be possible to define the unit *without ambiguity*,

(iii) The unit should be *reproducible*.

(iv) The value of unit should *not change with space and time*. (*i.e.*, it must always remain same everywhere).

The last three conditions (ii), (iii) and (iv) are essential for the unit to be accepted internationally.

Kinds of unit

Units are of *two* kinds : (i) Fundamental or basic units, and (ii) Derived units.

(i) Fundamental or basic units

A fundamental (or basic) unit is that which is independent of any other unit or which can neither be changed nor can be related to any other fundamental unit.

Examples: The units of mass, length, time, temperature, current and amount of substance are independent of each other. They can not be obtained from any other unit. These are the fundamental units.

(ii) Derived units

The units of quantities other than those measured in fundamental units, can be expressed in terms of the fundamental units and they are called the derived units. Thus

Derived units are those which depend on the fundamental units or which can be expressed in terms of the fundamental units.

Examples : (i) For the measurement of area, we need to measure length and breadth in the unit of length and then express area in a unit which is length × length or $(\text{length})^2$.

(ii) The volume is expressed in a unit which is length × length × length or $(\text{length})^3$.

(iii) The unit of speed of a moving body is obtained by dividing the unit of distance (*i.e.*, length) by the unit of time *i.e.*, it can be expressed in terms of the units of length and time.

Thus the units used to measure area, volume, speed, *etc*. are the derived units. More examples of derived units are given ahead in article 1.6.

1.2 SYSTEMS OF UNIT

In mechanics, ***length, mass*** and ***time*** are the *three* fundamental quantities. For the units of these three *basic quantities*, following systems have been used :

(i) **C.G.S. system (or French system) :** In this system, the unit of length is centimetre (cm), of mass is gram (g) and of time is second (s).

(ii) **F.P.S. system (or British system) :** In this system, the unit of length is foot (ft), of mass is pound (lb) and of time is second (s).

(iii) **M.K.S. system (or metric system) :** In this system, the unit of length is metre (m), of mass is kilogram (kg) and of time is second (s).

The above mentioned systems are now no longer in use and are only of historical importance. Now we use the S.I. system of units which is an enlarged and modified version of the metric system.

Systeme Internationale d'Unites (or S.I. system)

In 1960, the General Conference of Weights and Measures recommended that in addition to the units of length, mass and time, the units of temperature, luminous intensity, current and the amount of substance also be taken as fundamental units and the units of angle and solid angle as the complementary fundamental units. Thus in all, now there are *seven* fundamental units and *two* complementary fundamental units.

For **S.I. system,** the following table gives the fundamental quantities, their units and their standard symbols.

Fundamental quantities, units and symbols in S.I. system

Quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Luminous intensity	candela	cd
Electric current	ampere	A
Amount of substance	mole	mol*
Angle	radian	rd
Solid angle	steradian	st-rd

Use of prefix with a unit

For expressing large measurements, we use deca, hecto, kilo *etc*., as *prefixes* with the units.

** Nowadays 1 mol means 1 kg mol equal to $6{\cdot}02 \times 10^{26}$ entities (i.e., atoms or molecules or ions).*

The symbol and meaning of each prefix are given below.

Some prefixes used for big measurements

Prefix	Symbol	Meaning
deca	da	10^1
hecto	h	10^2
kilo	k	10^3
mega	M	10^6
giga	G	10^9
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}
zetta	Z	10^{21}
yotta	Y	10^{24}

The various small measurements are expressed by using the *prefixes* deci, centi, milli, micro, *etc.*, with the units. The symbol and meaning of each such prefix are given below.

Some prefixes used for small measurements

Prefix	Symbol	Meaning
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p (or μμ)	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yoeto	y	10^{-24}

Example : 2·5 GHz will mean $2{\cdot}5 \times 10^9$ Hz, 5·0 pF will mean $5{\cdot}0 \times 10^{-12}$ F, 5·0 MΩ will mean $5{\cdot}0 \times 10^6\ \Omega$, 2·0 ms will mean $2{\cdot}0 \times 10^{-3}$ s and so on.

1.3 UNITS OF LENGTH

S.I. unit of length

The S.I. unit of the length is metre (m).

> ***A metre was originally defined in 1889 as the distance between two marks drawn on a platinum-iridium (an alloy with 90% platinum and 10% iridium) rod kept at 0°C in the International Bureau of Weights and Measures at Sevres near Paris.***

Later, in 1960, the metre was re-defined as 1,650,763·73 times the wavelength of a specified orange-red spectral line in the emission spectrum of Krypton-86. It is also defined as : 'one metre is 1,553,164·1 times the wavelength of the red line in the emission spectrum of cadmium'.

> *In 1983, the metre was re-defined in terms of speed of light according to which one metre is the distance travelled by the light in* $\frac{1}{299,792,458}$ *of a second in air (or vacuum).*

Sub units of metre

For the measurement of small lengths, the metre is considered too big a unit. The most commonly used sub units of metre are **(i) centimetre** (cm), **(ii) millimetre** (mm), **(iii) micron** (μ) and **(iv) nanometre** (nm).

(i) centimetre (cm) : *One centimetre is one-hundredth part of a metre. i.e.,*

$$1 \text{ cm} = \frac{1}{100} \text{ m} = 10^{-2} \text{ m}$$

(ii) millimetre (mm) : *One millimetre is one-thousandth part of a metre. i.e.,*

$$1 \text{ mm} = \frac{1}{1000} \text{ m} = 10^{-3} \text{ m} = \frac{1}{10} \text{ cm}$$

(iii) micrometre or micron : *It is one-millionth* (10^{-6}) *part of a metre.* It is expressed by the symbol μ. It is also called micrometre (symbol μm).

$$1 \text{ micron } (\mu) = 10^{-6} \text{ metre} = 10^{-4} \text{ cm} = 10^{-3} \text{ mm.}$$

(iv) nanometer (nm) : *It is one billionth* (10^{-9} *th) part of a metre. i.e.,* 1 nm = 10^{-9} m.

Multiple units of metre

For the measurement of large lengths (or distances), the metre is considered as too small a unit. The most commonly used multiple unit of metre is kilometre.

kilometre (km) : *One kilometre is the one-thousand multiple of a metre. i.e.,*

$$1 \text{ km} = 1000 \text{ m (or } 10^3 \text{ m).}$$

Non-metric units of length

Bigger units : For the measurement of distance between two heavenly bodies, the kilometre is considered a too small unit. The commonly used units for this purpose are : **(i) astronomical unit** (A.U.), **(ii) light year** (ly) and **(iii) parsec.**

(i) Astronomical unit (A.U.) : *One astronomical unit is equal to the mean distance between the earth and the sun. i.e.,*

$$\boxed{1 \text{ A.U.} = 1{\cdot}496 \times 10^{11} \text{ metre}}$$

(ii) Light year (ly) : *A light year is the distance travelled by light in vacuum, in one year. i.e.,*

$$1 \text{ light year} = \text{speed of light} \times \text{time 1 year}$$
$$= 3 \times 10^8 \text{ m s}^{-1} \times (365 \times 24 \times 60 \times 60 \text{ s})$$
$$= 9{\cdot}46 \times 10^{15} \text{ m} = 9{\cdot}46 \times 10^{12} \text{ km}$$

The distance of stars from earth is generally expressed in light years. However, light minute and light second are its smaller units.

$$1 \text{ light minute} = 3 \times 10^8 \text{ m s}^{-1} \times 60 \text{ s} = 1{\cdot}8 \times 10^{10} \text{ m}$$
and $1 \text{ light second} = 3 \times 10^8 \text{ m s}^{-1} \times 1 \text{ s} = 3 \times 10^8 \text{ m}$

(iii) Parsec : *One parsec* is the distance from where the semi major axis of orbit of earth* (1 A.U.) *subtends an angle of one second.*

i.e., Parasec × 1 = 1 A.U.

or $$1 \text{ Parasec} = \frac{1{\cdot}496 \times 10^{11} \text{ m}}{(1/3600) \times (\pi/180)} = 3{\cdot}08 \times 10^{16} \text{ m}$$
$$= \frac{3{\cdot}08 \times 10^{16}}{9{\cdot}46 \times 10^{15}} \text{ ly} = 3{\cdot}26 \text{ ly}$$

Smaller units : To express the wavelength of light, size and separation between two molecules (or atoms), radius of orbit of electron, etc. a small size unit called the **Angstrom** (Å) is used, while the size of the nucleus is expressed by a still smaller unit called **fermi** (f).

(i) Angstrom (Å) : *It is 10^{-10}th part of a metre.* It is expressed by the symbol Å. *i.e.*,

$$1 \text{ Angstrom (Å)} = 10^{-10} \text{ metre}$$
$$= 10^{-8} \text{ cm} = 10^{-1} \text{ nm}$$
∴ $1 \text{ micron} = 10{,}000 \text{ Å}$
and $1 \text{ nm} = 10 \text{ Å}$

Nowadays, Å is outdated and nm is preferred over the Å. The wavelength of light, inter-atomic or inter-molecular separation, *etc*. are now commonly expressed in nm.

(ii) fermi (f) : *It is 10^{-15} th part of a metre. i.e.,*

$$1 \text{ fermi (f)} = 10^{-15} \text{ m}$$

The commonly used smaller and bigger units of length are summarized in the following table.

Smaller and bigger units of length

Smaller units	Value in metre	Bigger units	Value in metre
cm	10^{-2} m	km	10^3 m
		A.U.	$1{\cdot}496 \times 10^{11}$ m
mm	10^{-3} m	ly	$9{\cdot}46 \times 10^{15}$ m
μ (or μm)	10^{-6} m	parsec	$3{\cdot}08 \times 10^{16}$ m
nm	10^{-9} m		
Å	10^{-10} m		
f	10^{-15} m		

* *Parsec is constituted from the combination of two words, parallax (par) and arc-second (sec).*

1.4 UNITS OF MASS

S.I. unit of mass

The S.I. unit of mass is **kilogram** (kg).

In 1889, one kilogram was defined as the mass of a cylindrical piece of platinum-iridium alloy kept at International Bureau of Weights and Measures at Sevres near Paris.

However, the mass of 1 litre (= 1000 ml) of water at 4°C is also taken as 1 kilogram.

Sub units of kilogram

For measurement of small masses, kilogram (kg) is a bigger unit of mass. The smaller units of mass in common use are **(i) gram** (g) and **(ii) milligram** (mg).

(i) gram (g) : *One gram is the one-thousandth part of a kilogram i.e.,*

$$1 \text{ g} = \frac{1}{1000} \text{ kg} = 10^{-3} \text{ kg}$$
or $$1 \text{ kg} = 1000 \text{ g}$$

(ii) milligram (mg) : *One milligram is one-millionth (10^{-6}) part of a kilogram* or it is one-thousandth (10^{-3}) part of a gram. *i.e.*,

$$1 \text{ mg} = 10^{-6} \text{ kg} \quad \text{or} \quad 1 \text{ mg} = 10^{-3} \text{ g}$$

Multiple units of kilogram

The bigger common units of mass used in daily life are **(i) quintal** and **(ii) metric tonne**.

(i) quintal : It is one hundred times a kilogram,

i.e., 1 quintal = 100 kg

(ii) metric tonne : It is one-thousand times a kilogram. *i.e*,

1 metric tonne = 1000 kg = 10 quintal.

Non-metric unit of mass

The mass of atomic particles such as proton, neutron and electron is expressed in a unit called the **atomic mass unit** (symbol a.m.u) or the **unified atomic mass unit** (symbol u). It is defined as below :

1 a.m.u. (or u) is $\frac{1}{12}$ th the mass of one carbon-12 atom.

The mass of $6{\cdot}02 \times 10^{26}$ atoms of carbon –12 is 12 kg*.

* *Avogadro number $N = 6{\cdot}02 \times 10^{26}$ per kg atom.*

$\therefore$ 1 a.m.u (or u) $= \frac{1}{12} \times \frac{12}{6{\cdot}02\times10^{26}}$ kg

$= 1{\cdot}66 \times 10^{-27}$ kg

The mass of large heavenly bodies is measured in terms of **solar mass** where 1 solar mass is the mass of the sun, *i.e.*,

1 solar mass $= 2 \times 10^{30}$ kg

The commonly used smaller and bigger units of mass are summarized in the following table.

Smaller and bigger units of mass

Smaller units	Value in kg	Bigger units	Value in kg
g	10^{-3} kg	quintal	100 kg
mg	10^{-6} kg	metric tonne	1000 kg
u (or a.m.u.)	$1{\cdot}66 \times 10^{-27}$ kg	solar mass	2×10^{30} kg

1.5 UNITS OF TIME

S.I. unit of time

The S.I. unit of time is second (s).

A second is defined as 1/86400 th part of a mean solar day. i.e.,

$$1\ \text{s} = \frac{1}{86400} \times \text{one mean solar day}$$

One solar day is the time taken by the earth to complete one rotation on its own axis.

For many years, the above definition of second remained in use. But mean solar day varies over the years, therefore in 1956, scientists agreed to consider one year 1900 and 12 hours as the ephemeris time and one year 1900 to be equal to 365·2422 days. Thus,

$$\begin{aligned} 1 \text{ year } 1900 &= 365{\cdot}2422 \text{ days} \\ &= 365{\cdot}2422 \times 86400 \text{ s} \\ &= 31556925{\cdot}9747 \text{ s} \end{aligned}$$

Hence one second is defined as $\frac{1}{31556925{\cdot}9747}$ th part of the year 1900. *i.e.*,

$$1\ \text{s} = \frac{1}{31{,}556{,}925{\cdot}9747} \text{ th part of the year 1900.}$$

In 1964, a second was defined in terms of energy change in cesium atom as follows :

One second is the time interval of 9,192,631,770 vibrations of radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium - 133 atom.

Smaller units of time

The common smaller units of time are millisecond (ms), microsecond (μs), shake and nanosecond (ns) where

1 ms $= 10^{-3}$ s; 1 μs $= 10^{-6}$ s;

1 shake $= 10^{-8}$ s and 1 ns $= 10^{-9}$ s.

Bigger units of time

Sometimes second is a smaller unit of time and so we use other units of time such as **(i) minute, (ii) hour, (iii) day, (iv) month, (v) lunar month, (vi) year, (vii) leap year, (viii) decade, (ix) century and (x) millennium**. They are defined as below.

(i) minute (min) : *One minute is the duration of 60 second. i.e.,* 1 min = 60 s

(ii) hour (h) : *One hour is the duration of 60 minutes. i.e.,*

$$\begin{aligned} 1 \text{ h} &= 60 \text{ min} \\ &= 60 \times 60 \text{ s} = 3600 \text{ s} \end{aligned}$$

(iii) day : *The time taken by the earth to rotate once on its own axis is called a day*. One day is divided in 24 hours. Thus,

$$\begin{aligned} 1 \text{ day} &= 24 \text{ h} \\ &= 24 \times 60 \text{ min} = 1440 \text{ min} \\ &= 24 \times 60 \times 60 \text{ s} = 86400 \text{ s} \end{aligned}$$

(iv) month : The western or Gregorian Calendar has January, March, May, July, August, October and December each of 31 days; April, June, September and November each of 30 days and Feburary of 28 days (or 29 days in a leap year). To an approximation, a month is considered to be of 30 days and a year of 12 months to be of 365 days.

(v) lunar month : The western or Gregorian Calendar is based on the period of revolution of earth around the sun, but our Hindu (Vikram and Shak) and Muslim (Hizri) Calendars are based on the phases of moon as seen from our earth. In these calendars, one month is the time of one lunar cycle which is nearly 29.5 days. The period of 12 lunar months is 354·37 days.

(vi) year (yr) : *One year is defined as the time in which the earth completes one revolution around the sun.* The period of revolution of earth around the sun is nearly 365 days. Thus,

$$\begin{aligned} 1 \text{ yr} &= 365 \text{ days} \\ &= 365 \times 86400 \text{ s} = 3{\cdot}1536 \times 10^7 \text{ s} \end{aligned}$$

(vii) Leap year : *A leap year is the year in which the month of February is of 29 days, i.e.,*

1 Leap year = 366 days

Since the exact period of revolution of the earth around the sun is 365·2422 days, therefore to compensate for the excess of 0·2422 days in a year, the English calendar has been modified as follows :

Every fourth year (*i.e.*, the year divisible by 4) has one day extra in the month of February (*i.e.*, the February then has 29 days) and so it is the leap year. For example, the years like 1904, 1908, ……, 2000, 2004, 2008, 2012, were the leap years and the years 2016, 2020, ... will also be the leap years. The exception is :

The century years (*i.e.*, 1800, 1900 etc.) though divisible by 4, are not the leap years *e.g.* the year 2100 will not be a leap year. But the years which are divisible by 400, will be the leap year. e.g. the year 2000 was a leap year and the year 2400 will also be a leap year.

(viii) Decade : *A decade is of 10 years.* Thus,

1 Decade = 10 years = $3{\cdot}1536 \times 10^8$ s

(ix) Century : *A century is of 100 years.* In a century, there will be 24 years each of 366 days and 76 years each of 365 days. Thus,

1 Century = 100 years

= (24 × 366 + 76 × 365) days

= 36524 days = $3{\cdot}16 \times 10^9$ s.

(x) Millennium : *A millennium is of 1000 years, i.e.* 1 Millennium = $3{\cdot}16 \times 10^{10}$ s

The commonly used bigger units of time are summarized in the following table.

Bigger units of time

Bigger units	Value in second	Bigger units	Value in second
min	60 s	year	$3{\cdot}1536 \times 10^7$ s
h	3600 s	Decade	$3{\cdot}1536 \times 10^8$ s
day	86400 s	Century	$3{\cdot}16 \times 10^9$ s
month	$2{\cdot}592 \times 10^6$ s	Millennium	$3{\cdot}16 \times 10^{10}$ s

1.6 SOME EXAMPLES OF DERIVED UNITS

We have read that apart from the seven fundamental quantities used in S.I. system such as length, mass, time, temperature, luminous intensity, current and the amount of substance, the units of all other physical quantities are obtained in terms of the fundamental units. The units so obtained are called the derived units. Some examples of derived units are listed below.

Derived units of some physical quantities

Quantity	Definition	Derived unit	Abbreviation/symbol
1. Area	length × breadth	metre × metre	m^2
2. Volume	length × breadth × height	metre × metre × metre	m^3
3. Density	$\frac{\text{mass}}{\text{volume}}$	$\frac{\text{kilogram}}{(\text{metre})^3}$	$kg\ m^{-3}$
4. Speed or velocity	$\frac{\text{distance}}{\text{time}}$	$\frac{\text{metre}}{\text{second}}$	$m\ s^{-1}$
5. Acceleration	$\frac{\text{velocity}}{\text{time}}$	$\frac{\text{metre/second}}{\text{second}}$	$m\ s^{-2}$
6. Force	mass × acceleration	kilogram × $\frac{\text{metre}}{(\text{second})^2}$ or newton	$kg\ m\ s^{-2}$ or N
7. Work or energy	force × displacement	kilogram × $\frac{\text{metre}}{(\text{second})^2}$ × metre or joule	$kg\ m^2\ s^{-2}$ or J
8. Momentum	mass × velocity	kilogram × $\frac{\text{metre}}{\text{second}}$ or newton × second	$kg\ m\ s^{-1}$ or N s

9. Moment of force or torque	force × distance	kilogram × $\frac{\text{metre}}{(\text{second})^2}$ × metre or newton-metre	kg m^2 s^{-2} or N m
10. Power	$\frac{\text{work}}{\text{time}}$	$\frac{\text{kilogram}\,(\text{metre})^2}{(\text{second})^2}$ / second or joule/second or watt	kg m^2 s^{-3} or J s^{-1} or W
11. Pressure	$\frac{\text{force}}{\text{area}}$	kilogram × $\frac{\text{metre}}{(\text{second})^2}$ / $(\text{metre})^2$ or newton/$(\text{metre})^2$ or pascal	kg m^{-1} s^{-2} or N m^{-2} or Pa
12. Frequency	$\frac{1}{\text{time period}}$	$\frac{1}{\text{second}}$ or second^{-1} or hertz	s^{-1} or Hz
13. Electric charge	current × time	ampere × second or coulomb	A s or C
14. Electric potential or electromotive force (e.m.f.)	$\frac{\text{work}}{\text{charge}}$	$\frac{\text{kilogram} \times \text{metre}^2}{\text{second}^2}$ / ampere × second or joule/coulomb or volt	kg m^2 A^{-1} s^{-3} or J C^{-1} or V
15. Electrical resistance	$\frac{\text{potential}}{\text{current}}$	$\frac{\text{kilogram} \times \text{metre}^2}{\text{ampere} \times \text{second}^3}$ / ampere or $\frac{\text{volt}}{\text{ampere}}$ or ohm	kg m^2 A^{-2} s^{-3} or V A^{-1} or Ω
16. Electrical power	potential × current	volt × ampere or watt	V A or W

From the above list, it can be noted that some derived units are complex when they are expressed in terms of fundamental units. Such derived units have been given special names after the name of the scientist who has contributed in that field. For example, newton for force, joule for work (or energy), watt for power, pascal for pressure, hertz for frequency, coulomb for electric charge, volt for electric potential (or e.m.f.) and ohm for electrical resistance. Full name of such a unit is always written with small initial letter, while its symbol is written with the first capital letter.

1.7 GUIDELINES FOR WRITING THE UNITS

Conventionally following rules are observed while writing the unit of a physical quantity :

(i) The symbol for a unit, which is not named after a scientist, is written in small letter. *For example*, symbol for metre is m, for second is s, for kilogram is kg and so on.

(ii) The symbol for a unit, which is named after a scientist, is written with first letter of his name in capital. *For example*, N for newton, J for joule, W for watt, Pa for pascal, Hz for hertz, C for coulomb and V for volt.

(iii) The full name of the unit, irrespective of the fact whether it is named after a scientist or not, is always written with a lower initial letter e.g., unit for mass is written as kilogram, not as Kilogram; unit of length is written as metre, not as Metre; unit of force is written as newton and not as Newton ; unit of energy is written as joule and not as Joule; unit of power is written as watt and not as Watt.

(iv) A compound unit formed by multiplication of two or more units is written after putting a dot, cross or leaving a space between the two symbols. For example, the unit of torque is written as N.m or N × m or N m.

(v) Negative power is used for compound units, which are formed by dividing one unit by the other.

Examples :

(1) The unit of velocity is $\frac{\text{metre}}{\text{second}}$. It is expressed as m s^{-1}.

(2) The unit of power is $\frac{\text{joule}}{\text{second}}$. It is expressed as J s^{-1}.

(vi) A unit in its short form is never written in plural. *For example*, 10 metres can not be written as 10 ms, because ms would mean millisecond.

(vii) To avoid powers of ten in the magnitude of a quantity, prefix can be used with its unit. But a unit must not be written with more than one prefixes. *For example*, instead of kMW, we must write GW.

(viii) When prefix is used with the symbol of unit, the prefix and symbol combined becomes the new symbol of the unit. *For example*, km^3 means $(10^3 \text{ m})^3 = 10^9 \text{ m}^3$; it does not mean 10^3 m^3.

EXAMPLES

1. (i) The mass of an atom of oxygen is 16·0 u. Express it in kg.

(ii) The mass of a molecule of hydrogen is $3{\cdot}332 \times 10^{-27}$ kg. Find the mass of 1 kg mol of hydrogen gas.

(i) Given : mass of one atom of oxygen = 16·0 u

1 u = $1{\cdot}66 \times 10^{-27}$ kg

∴ The mass of an atom of oxygen

= $16{\cdot}0 \times 1{\cdot}66 \times 10^{-27}$ kg

= **2656×10^{-26} kg**

(ii) Given : mass of a molecule of hydrogen

= $3{\cdot}332 \times 10^{-27}$ kg

1 kg mol of hydrogen gas will contain $6{\cdot}02 \times 10^{26}$ molecules of hydrogen

∴ The mass of 1 kg mol of hydrogen gas

= $(6{\cdot}02 \times 10^{26}) \times 3{\cdot}332 \times 10^{-27}$ kg

= **2·0 kg**

2. The size of a particle is 4·6 μ. Express it in metre.

Given : size of a particle = 4·6 μ

Since 1 μ = 10^{-6} m

∴ Size of a particle = **$4{\cdot}6 \times 10^{-6}$ m**

3. It takes 5 years for light to reach the earth from a star. Express the the distance of star from the earth in (i) light year, (ii) km. Take speed of light = 3×10^8 m s^{-1} and 1 year = $3{\cdot}1 \times 10^7$ s.

(i) The distance travelled by light in 1 year is called 1 light year. Thus the distance travelled by light in 5 years = 5 light year.

∴ Distance of star from the earth = **5 light year.**

(ii) 1 light year = speed of light × time 1 year

= $(3 \times 10^8 \text{ m s}^{-1}) \times (3{\cdot}1 \times 10^7 \text{ s})$

= $9{\cdot}3 \times 10^{15}$ m = $9{\cdot}3 \times 10^{12}$ km

∴ Distance of star from the earth = $5 \times 9{\cdot}3 \times 10^{12}$ km

= **$4{\cdot}65 \times 10^{13}$ km**

4. The average mass of an atom of uranium is $3{\cdot}9 \times 10^{-25}$ kg. Find the number of atoms in 1 g of uranium .

Given : mass of one atom of uranium

= $3{\cdot}9 \times 10^{-25}$ kg = $3{\cdot}9 \times 10^{-22}$ g

(since 1 kg = 10^3 g)

∴ Number of atoms in 1 g uranium

$$= \frac{1}{3{\cdot}9 \times 10^{-22}} = \mathbf{2{\cdot}6 \times 10^{21}}$$

EXERCISE 1(A)

1. What is meant by measurement ?
2. What do you understand by the term unit ?
3. What are the *three* requirements for selecting a unit of a physical quantity ?
4. Name the *three* fundamental quantities.
5. Name the *three* systems of unit and state the various fundamental units in them.
6. Define a fundamental unit.
7. What are the fundamental units in S.I. system ? Name them along with their symbols.
8. Explain the meaning of derived unit with the help of *one* example.
9. Define standard metre.
10. Name *two* units of length which are bigger than a metre. How are they related to the metre ?
11. Write the names of *two* units of length smaller than a metre. Express their relationship with metre.

12. How is nanometre related to Angstrom ?
13. Name the *three* convenient units used to measure length ranging from very short to very long value. How are they related to the S.I. unit ?
14. Name the S.I. unit of mass and define it.
15. Complete the following :
    (a) 1 light year = ...m
    (b) 1 m = ... Å
    (c) 1 m = ...μ
    (d) 1 micron = ... Å
    (e) 1 fermi = ... m

Ans. (a) $9{\cdot}46 \times 10^{15}$ (b) 10^{10} (c) 10^6 (d) 10^4 (e) 10^{-15}

16. State *two* units of mass smaller than a kilogram. How are they related to the kilogram ?
17. State *two* units of mass bigger than a kilogram. Give their relationship with the kilogram.
18. Complete the following :
    (a) 1 g = ... kg
    (b) 1 mg = ... kg
    (c) 1 quintal = ... kg
    (d) 1 a.m.u (or u) = ... kg

    Ans. (a) 10^{-3} (b) 10^{-6} (c) 100 (d) $1{\cdot}66 \times 10^{-27}$
19. Name the S.I. unit of time and define it.
20. Name *two* units of time bigger than a second. How are they related to the second ?
21. What is a leap year ?
22. 'The year 2016 will have February of 29 days'. Is this statement true ? **Ans.** Yes
23. What is a lunar month ?
24. Complete the following :
    (a) 1 nano second = ...s.
    (b) 1 μs = ...s.
    (c) 1 mean solar day = ...s.
    (d) 1 year = ...s.

    Ans. (a) 10^{-9} (b) 10^{-6} (c) 86400 (d) $3{\cdot}15 \times 10^7$
25. Name the physical quantities which are measured in the following units :
    (a) u (b) ly (c) ns (d) nm

    Ans. (a) mass (b) distance (or length) (c) time (d) length
26. Write the derived units of the following :
    (a) speed (b) force
    (c) work (d) pressure.

    Ans. (a) $m\ s^{-1}$ (b) $kg\ m\ s^{-2}$ (c) $kg\ m^2\ s^{-2}$ (d) $kg\ m^{-1}\ s^{-2}$
27. How are the following derived units related to the fundamental units ?
    (a) newton (b) watt
    (c) joule (d) pascal.

    Ans. (a) $kg\ m\ s^{-2}$ (b) $kg\ m^2\ s^{-3}$ (c) $kg\ m^2\ s^{-2}$ (d) $kg\ m^{-1}\ s^{-2}$
28. Name the physical quantities related to the following units :
    (a) km^2 (b) newton (c) joule
    (d) pascal (e) watt

    Ans. (a) area (b) force (c) energy (d) pressure (e) power

Multiple choice type :

1. The fundamental unit is :
   (a) newton (b) pascal
   (c) hertz (d) second. **Ans.** (d) second
2. Which of the following unit is not a fundamental unit :
   (a) metre (b) litre
   (c) second (d) kilogram.

   Ans. (b) litre
3. The unit of time is :
   (a) light year (b) parsec
   (c) leap year (d) angstrom.

   Ans. (c) leap year
4. 1 Å is equal to :
   (a) 0·1 nm (b) 10^{-10} cm
   (c) 10^{-8} m (d) 10^4 μ.

   Ans. (a) 0·1 nm
5. ly is the unit of :
   (a) time (b) length
   (c) mass (d) none of these.

   Ans. (b) length

Numericals :

1. The wavelength of light of a particular colour is 5800 Å. Express it in (a) nanometre and (b) metre.

   Ans. (a) 580 nm, (b) $5{\cdot}8 \times 10^{-7}$ m
2. The size of a bacteria is 1 μ. Find the number of bacteria in 1 m length. **Ans.** 10^6
3. The distance of a galaxy is $5{\cdot}6 \times 10^{25}$ m. Assuming the speed of light to be $3 \times 10^8\ m\ s^{-1}$ find the time taken by light to travel this distance.

   [**Hint :** Time taken = $\frac{\text{Distance travelled}}{\text{speed}}$]

   Ans. $1{\cdot}87 \times 10^{17}$ s
4. The wavelength of light is 589 nm. What is its wavelength in Å ?

   Ans. 5890 Å

5. The mass of an oxygen atom is 16·00 u. Find its mass in kg. **Ans.** $2{\cdot}656 \times 10^{-26}$ kg

6. It takes time 8 min for light to reach from the sun to the earth surface. If speed of light is taken to be 3×10^8 m s^{-1}, find the distance from the sun to the earth in km. **Ans.** $1{\cdot}44 \times 10^8$ km

7. 'The distance of a star from the earth is 8·33 light minutes.' What do you mean by this statement ? Express the distance in metre. **Ans.** $1{\cdot}5 \times 10^{11}$ m

(B) MEASUREMENT OF LENGTH

1.8 LEAST COUNT OF A MEASURING INSTRUMENT

The measurement of a physical quantity (such as length, mass, time, current, etc.), requires an instrument. For example, a metre rule (or vernier callipers) is used for length, a balance for mass, a watch for time, a thermometer for temperature and an ammeter for current. Each instrument has a definite limit for accuracy of measurement which is expressed in terms of its least count.

The least count of an instrument is the smallest measurement that can be taken accurately with it.

A measuring instrument is provided with a graduated scale for measurement and *the least count is the value of one smallest division on its scale. For example*, the least count of a metre rule is the value of its one division which is one-tenth of a centimetre (or 1 mm). The least count of a stop watch is 0·5 second if there are 10 divisions between 0 and 5 s mark. The least count of an ammeter having 5 divisions between the marks 0 and 1 A, is 0·2 A.

Smaller the least count of an instrument, more precise is the measurement made by using it.

1.9 MEASUREMENT OF LENGTH

Generally a metre rule having its zero mark at one end and 100 cm mark at the other end is used to measure the length of an object. It has 10 subdivisions in each one centimetre length, so the value of its one small division is 1 mm (or 0·1 cm). Thus a metre rule can be used to measure length correct only up to 1 mm *i.e.*, one decimal place of a centimetre. It cannot measure length with still more accuracy *i.e.,* up to second decimal place of a centimetre. The reason is that if one end of object lies between two small divisions on metre rule, the mark nearer the end of the object is read and thus its length correct up to the second decimal point can not be measured. However it becomes possible with the help of the *vernier callipers and screw gauge*. They are more accurate since they have least count smaller than 0·1 cm.

1.10 PRINCIPLE OF VERNIER

Pierre Vernier devised a method by which length up to 2nd decimal place of a cm *i.e.,*correct up to 0·1 mm (or 0·01 cm) can be measured. In this technique, *two* scales are used. One scale, called the ***main scale***, is fixed, while the other scale, called the ***vernier scale***, slides along the main scale.

The main scale is graduated with value of one division on it equal to 1 mm. The graduations on the vernier scale are such that the length of n divisions on vernier scale is equal to the length of $(n - 1)$ divisions of the main scale. Generally, a vernier scale has 10 divisions and the total length of these 10 divisions is equal to the length of $10 - 1 = 9$ divisions of the main scale *i.e.,* equal to 9 mm. Thus each division of the vernier scale is of length 0·9 mm (*i.e.*, smaller in size by $\frac{1}{10}$ mm than a division on the main scale). This difference is utilised as least count for the measurement.

Least count of vernier or vernier constant

The least count of vernier is equal to the difference between the values of one main scale division and one vernier scale division. It is also called the ***vernier constant***. Thus,

**Vernier constant or least count of vernier,
L.C. = value of 1 main scale division
– value of 1 vernier scale division.** ...(1.1)

Let n divisions on vernier be of length equal to that of $(n - 1)$ divisions on main scale and the value of 1 main scale division be x. Then

Value of n divisions on vernier $= (n - 1)x$

$\therefore$ Value of 1 division on vernier $= \frac{(n-1)x}{n}$

Hence from eqn. (1.1),

$$\text{L.C.} = x - \frac{(n-1)x}{n} = \frac{x}{n}$$

i.e., $$\boxed{\text{L.C.} = \frac{\text{Value of one main scale division } (x)}{\text{Total number of divisions on vernier } (n)}}$$ ...(1.2)

Thus, the least count of a vernier is obtained simply by dividing the value of one division of main scale by the total number of divisions on vernier scale.

Example : Fig. 1.1 shows a main scale graduated to read up to 1 mm and a vernier scale on which the length of 10 divisions is equal to the length of 9 divisions on main scale. We are to find its least count.

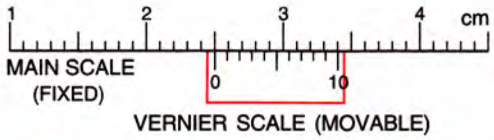

Fig 1.1 To find the least count of the vernier

In Fig. 1.1,

Value of 1 division of main scale (x) = 1 mm.

Total number of divisions on vernier (n) = 10

$\therefore$ From eqn. (1.2),

$$\text{L.C.} = \frac{x}{n} = \frac{1\text{ mm}}{10} = 0{\cdot}1 \text{ mm} = 0{\cdot}01 \text{ cm}.$$

Use of vernier scale

Fig. 1.2 illustrates the use of a vernier scale. The two scales (main scale and vernier scale) are so made that *when the movable vernier scale touches the fixed end, its zero mark coincides with the zero mark of the main scale*. The rod whose length is to be measured, is placed along the main scale and vernier scale is moved so as to hold the rod between the fixed end and the movable vernier scale. In this position, the zero mark of the vernier scale is ahead of 1·2 cm mark on main scale. Thus the actual length of the rod = 1·2 cm + the length *ab* (*i.e.*, the length between the 1·2 cm mark on main scale and 0 mark on vernier scale). The length *ab* cannot be measured

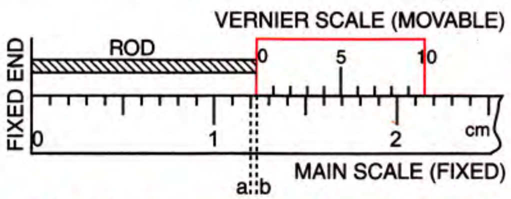

Fig. 1.2 Measurement with vernier scale

by the main scale as its value is less than one division marked on the main scale.

To measure the length *ab,* first we find the least count of the vernier scale. It is $\frac{0{\cdot}1}{10}$ cm = 0·01 cm. Then we note that p^{th} division of vernier scale which coincides (or which is in line) with any division of the main scale. The product of this number of vernier division *p* with the least count gives the length *ab.** This is called the *vernier reading*. Thus

$$\boxed{\begin{aligned} &\text{length } ab = \text{vernier reading} = p \times \text{least count}, \\ &\text{and Total reading} = \text{main scale reading} \\ &\qquad\qquad + \text{vernier reading} \end{aligned}}$$ ..(1.3)

In Fig. 1.2, the main scale reading is 1·2 cm and 4th division of vernier scale coincides with a main scale division and so the length *ab* (or vernier reading) is $4 \times 0{\cdot}01$ cm = 0·04 cm.

Hence the length of rod is $1{\cdot}2 + 0{\cdot}04 = 1{\cdot}24$ cm.

1.11 VERNIER CALLIPERS

A vernier callipers is also called the *slide callipers*. It is used to measure the length of a rod, the diameter of a sphere, the internal and external diameters of a hollow cylinder, the depth of a small beaker (or bottle), etc.

(a) *Description*

A vernier callipers is shown in Fig. 1.3. It consists of a long and thin steel strip provided with a jaw J_1 at one end. On the strip, a scale is graduated with the value of one division equal to 1 mm. This is the *main scale*. Another small steel strip provided with a jaw J_2 at its end, can slide over the main scale strip. This strip also has a scale graduated with 10 divisions on it, the length of which is equal to 9 mm. It is called the *vernier scale*. For more precise measurement, the vernier scale can have 20, 25 or 50 divisions marked on it and the total length of vernier divisions will be equal to the length of one division less (*i.e.*, 19, 24 or 49 divisions respectively) on the main scale. The vernier scale which slides over the main scale, can

* If p^{th} division of vernier scale coincides with any division of main scale, then

ab + length of *p* divisions on vernier scale = length of *p* divsions on main scale

length *ab* = length of *p* divisions on main scale − length of *p* divisions on vernier scale

= *p* × (length of 1 division on main scale − length of 1 division on vernier scale)

= *p* × L.C.

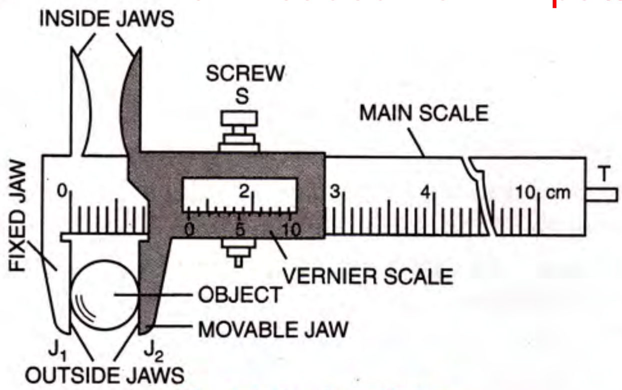

Fig. 1.3 Vernier callipers

be fixed at any position on the main scale with the help of a screw *S*. Both jaws are parallel to each other and are projected on either side of the main scale to hold the given object. The lower jaws are called the *outside jaws* and they are used to measure the length of a rod, diameter of a sphere or external diameter of a cylinder. The upper jaws are called the *inside jaws* which are used to measure the internal diameter of a hollow cylinder (or pipe).

A vernier callipers is also provided with a thin and long strip *T* attached to the vernier scale strip, at the back of the main scale strip. It slides with the vernier scale. When jaws J_1 and J_2 are in contact, the end of the strip *T* touches the end at the back of the main scale strip. The strip *T* is used to measure the depth of a small beaker (or bottle).

The table below gives the main parts of a vernier callipers with their functions.

Vernier callipers — main parts and their functions

Part	Function
1. Outside jaws	To measure the length of a rod, diameter of a sphere, external diameter of a hollow cylinder.
2. Inside jaws	To measure the internal diameter of a hollow cylinder or pipe.
3. Strip	To measure the depth of a beaker or a bottle.
4. Main scale	To measure length correct up to 1 mm.
5. Vernier scale	Helps to measure length correct up to 0·1 mm.

(b) ***Least count of vernier callipers***

The least count of vernier callipers is equal to the difference between the values of one main scale division and one vernier scale division. It is calculated by using the eqn. (1.2), *i.e.*,

$$\text{L.C.} = \frac{\text{Value of one main scale division } (x)}{\text{Total number of divisions on vernier } (n)}$$

The least count of a vernier callipers can be decreased by (i) increasing the number of divisions on the vernier scale and (ii) decreasing the value of one division on main scale.

(c) ***Zero error in vernier callipers***

On bringing the movable jaw J_2 in contact with the fixed jaw J_1, the zero mark of the vernier scale should coincide with the zero mark of the main scale. If it is so, the vernier is said to be *free from zero error.* In this condition, the end of strip *T* also touches the end of the main scale strip.

But sometimes there is a mechanical error in the vernier callipers due to which the zero mark of the vernier scale does not coincide with the zero mark of the main scale when the two jaws J_1 and J_2 are in contact. It is then said to have *zero error*. In such a case, *the zero error is equal to the length between the zero mark of the main scale and the zero mark of the vernier scale.* It is necessary to account for this error for a correct (or true) measurement from this instrument.

Kinds of zero error : The zero error is of the following *two* kinds :

(i) Positive zero error, and

(ii) Negative zero error.

(i) Positive zero error : On bringing the two jaws together, if zero mark of the vernier scale is on the ***right of zero mark*** of the main scale, the zero error is said to be ***positive.*** Fig. 1.4 shows the two scales of a vernier callipers with positive zero error. The positive zero error is equal to the length between the zero mark of the vernier scale from the zero mark of the main scale.

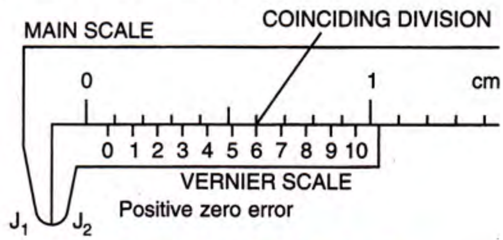

Fig. 1.4 Positive zero error

To find this error, we note that division of the vernier scale which coincides with any division of the main scale. The number of this vernier division when multiplied by the least count of the vernier, gives the zero error.

For example, for the scales shown in Fig. 1.4, the least count is 0·01 cm and the 6^{th} division of

vernier scale coincides with a main scale division.

$\therefore$ Zero error $= +\,6 \times$ L.C. $= +\,6 \times 0{\cdot}01$ cm
$= +\,0{\cdot}06$ cm.

(ii) Negative zero error : On bringing the two jaws together, if zero mark of the vernier scale is to the ***left of zero mark*** of the main scale, the zero error is said to be ***negative***. Fig. 1.5 shows the two scales of a vernier callipers with negative zero error. The negative zero error is equal to the length between the zero mark of the main scale from the zero mark of the vernier scale.

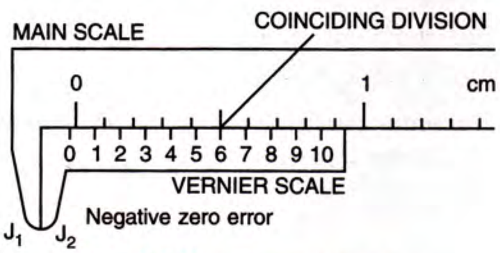

Fig. 1.5 Negative zero error

To find this error, we note that division of the vernier scale which coincides with any division of the main scale. The number of this vernier division is subtracted from the total number of divisions on the vernier scale and then the difference is multiplied by the least count.

In Fig. 1.5, the least count is 0·01 cm and the sixth division of the vernier scale coincides with a certain division of the main scale. The total number of divisions on vernier are 10.

$\therefore$ Zero error $= -\,(10 - 6) \times$ L.C.
$= -\,4 \times 0{\cdot}01$ cm $= -\,0{\cdot}04$ cm.

(d) *Correction due to zero error i.e., correct measurement with a vernier callipers having a zero error*

To get the correct reading, *the zero error with its proper sign is always subtracted from the observed reading. i.e.,*

Correct reading = Observed reading – Zero error (with sign)

...(1.4)

Thus the positive zero error gets subtracted from the observed reading, while the negative zero error gets added to the observed reading.

(e) *Measurement of length of an object with a vernier callipers*

Procedure :

(i) Find the least count and zero error of the vernier callipers.

(ii) Move the jaw J_2 away from the jaw J_1 and place the object to be measured, between the jaws J_1 and J_2. Move the jaw J_2 towards the jaw J_1 till it touches the object. Tighten the screw S to fix the vernier scale in its position.

(iii) Note the main scale reading.

(iv) Note that division p on vernier scale which coincides or is in line with any division of the main scale. Multiply this vernier division p with the least count. This is the vernier scale reading *i.e.*, Vernier scale reading $= p \times$ L.C.

(v) Add the vernier scale reading to the main scale reading. This gives the observed length.

(vi) Repeat it *two* times and record the observations as below.

Observations :

Total number of divisions on vernier scale
$n = ...$

Value of one division on main scale
$x = ...$ cm

Least count (L.C.) $= \dfrac{x}{n} = ...$ cm

Zero error $= ....$ cm

S. No.	*Main scale reading a (in cm)*	*Vernier divsion coinciding p*	*Vernier scale reading b = p × L.C. (in cm)*	*Observed length = a + b (in cm)*
1.				
2.				
3.				

Mean observed length = ... cm

From the mean observed length, subtract the zero error, it any, with its proper sign to obtain the true measurement of the length of the given object. Thus,

Observed length = main scale reading + (vernier division p coinciding with any division on the main scale) × least count.
True length = observed length – zero error (with sign)

Example : Fig. 1.6 illustrates how to read a vernier callipers.

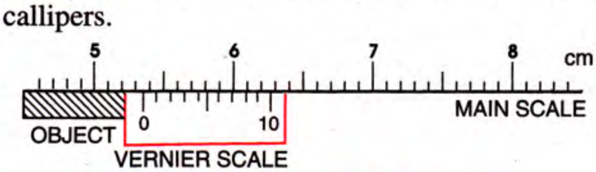

Fig. 1.6 To read a vernier callipers

In Fig. 1.6,
The least count of vernier callipers = 0·01 cm
Main scale reading = 5·3 cm

6th division of vernier scale coincides with a division on main scale *i.e.*, $p = 6$

$\therefore$ Vernier scale reading $= 6 \times 0{\cdot}01 = 0{\cdot}06$ cm

$$\begin{aligned}\text{Hence observed reading} &= \text{main scale reading} + \text{vernier scale reading}\\ &= 5{\cdot}3 \text{ cm} + 0{\cdot}06 \text{ cm}\\ &= 5{\cdot}36 \text{ cm}\end{aligned}$$

If the vernier callipers is free from zero error, then true length = 5·36 cm.

1.12 PRINCIPLE OF A SCREW

An ordinary screw has threads on it at an equal distance along its length. On rotating the head of the screw, it moves forward or backward linearly along its axis. The linear distance which the screw moves in one round, is equal to the distance between the two consecutive threads on it. This distance is called the ***pitch*** of the screw. Thus,

> ***The pitch of a screw is the distance moved along its axis by the screw in one complete rotation of its head.***

Generally, the pitch of a screw is 1 mm or 0·5 mm.

To use the linear movement of a screw for measuring small lengths, the head of the screw is made large and it is graduated along its circumference. Normally it has 50 or 100 equal divisions on it. This is called the ***circular*** or ***head scale***.

Least count of a screw

If pitch of a screw is 1 mm, and it has 100 divisions on its head, then on rotation of 100 divisions of its circular scale, the pointed end of the screw moves by a distance equal to 1 mm. Hence the distance moved by the screw along its axis, on rotation of 1 division of the circular scale will be $\frac{1\text{ mm}}{100} = 0{\cdot}01$ mm $= 0{\cdot}001$ cm. This is the least distance which can be measured by the movement of screw and is therefore called its ***least count***. Thus,

> ***The least count of a screw is the distance moved along the axis by it in rotating the circular scale by one division.***

The least count of a screw can be obtained by dividing the pitch of the screw by the total number of divisions on its circular scale. *i.e.*,

$$L.C. = \frac{\textit{Pitch of screw}}{\textit{Total number of divisions on circular scale}} \quad ..(1.5)$$

Examples :

(1) If a screw moves by 1 mm in one rotation and it has 100 divisions on its circular scale, then pitch of the screw = 1 mm and least count of the screw $= \frac{1\text{mm}}{100} = 0{\cdot}01$ mm $= 0{\cdot}001$ cm.

(2) If a screw moves by 1 mm in two rotations and its circular scale has 50 divisions, then pitch of the screw $= \frac{1}{2}$ mm (or 0·5 mm) and the least count of the screw $= \frac{0{\cdot}5\text{ mm}}{50} = 0{\cdot}01$ mm $= 0{\cdot}001$ cm.

(3) If a screw moves by 1 mm in two rotations and its circular scale has 500 divisions, then pitch of the screw is $\frac{1}{2}$ mm (or 0·5 mm) and the least count of the screw is equal to $\frac{0{\cdot}5\text{ mm}}{500} = 0{\cdot}001$ mm (or 1 μ).

1.13 SCREW GAUGE

A screw gauge works on the principle of a screw. It is used to measure the diameter of a wire or thickness of a paper, etc., usually up to an accuracy of third decimal place of a cm (*i.e.*, correct up to 0·001 cm). However, the least count of a micrometer screw gauge is 1 μ (or 0·0001 cm).

(a) ***Description***

A screw gauge is shown in Fig. 1.7. It has a U-shaped frame with a flat end *A* called the *stud* at one end and a *nut N* with a cylindrical sleeve at the other end. *Both the nut and sleeve are threaded from inside*. A screw with its one flat end *B* can be moved inside the nut *N* by rotating its head which is in form of a hollow cylinder (or *thimble*) provided at

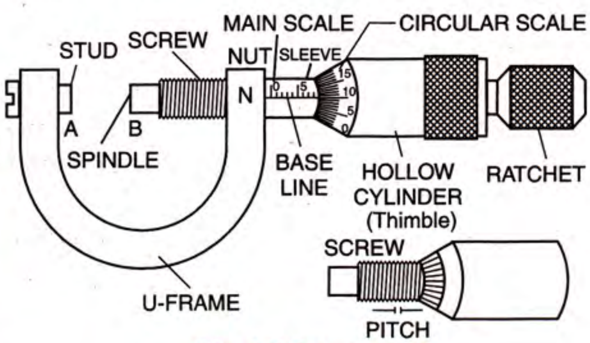

Fig. 1.7 Screw gauge

the other end of the screw. A reference line or *base line* graduated in mm is drawn on the cylindrical sleeve, parallel to the axis of the screw. This is the *main scale*. The hollow cylinder (or thimble) is also graduated and it is divided into 100 equal parts. This is the *circular scale* (or *head scale*). The thimble is attached with a *ratchet* by a spring. *The screw is always rotated by turning the ratchet.* As soon as the flat end *B* of the screw comes in contact either with the stud *A* or with the object in between *A* and *B*, any further rotation of the ratchet does not move the screw linearly to press *B* against *A* (or the object). Thus a ratchet helps in holding the given object *gently* between the stud *A* and the end *B* of the screw.

The table below gives the main parts of a screw gauge and their functions.

Screw gauge — main parts and their functions

Part	Function
1. Ratchet	To advance the screw by turning it till the object is gently held between the stud and spindle of the screw.
2. Sleeve	To mark main scale and base line.
3. Thimble	To mark circular scale.
4. Main scale	To read length correct up to 1 mm.
5. Circular scale	Helps to read length correct up to 0·01 mm.

(b) *Pitch and least count of a screw gauge*

The pitch of a screw gauge is the linear distance moved by its screw on the main scale when the circular scale is given one complete rotation.

However, the least count of a screw gauge is the linear distance moved by its screw along the main scale when the circular scale is rotated by one division on it. Thus,

Least count of screw gauge,

$$\text{L.C.} = \frac{\text{Pitch of the screw gauge}}{\text{Total number of divisions on its circular scale}} \quad ...(1.6)$$

Way to decrease the least count of a screw gauge : The least count of a screw gauge can be decreased by (i) decreasing the pitch and (ii) increasing the total number of divisions on the circular scale. In Fig. 1.8, a screw gauge is designed to have 20 divisions in 1 cm on main scale and 500 divisions on its circular scale. Thus the value of one division on main scale is $\frac{1}{20}$ cm = 0·05 cm or 0·5 mm. The screw moves 1 division along the main scale in one complete rotation of circular scale so its pitch is 0·5 mm and the least count is $\frac{0{\cdot}5 \text{ mm}}{500}$ = 0·001 mm or 10^{-6} m. Therefore it is called the micrometer screw gauge. Such a screw gauge is used where high degree of accuracy is required *e.g.* in optical measurements.

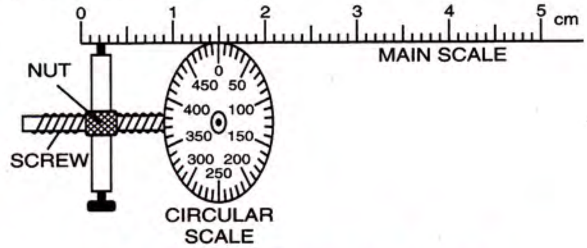

Fig. 1.8 Micrometer screw gauge

(c) *Zero error in a screw gauge*

On bringing the flat end *B* of the screw in contact with the stud *A*, if the zero mark of circular scale coincides with the base line of main scale, the screw gauge is said to be *free from zero error.*

But sometimes, due to mechanical error, on bringing the stud *A* in contact with the stud *B*, the zero mark of the circular scale is either below or above the base line of main scale, then the screw gauge is said to have a zero error.

Kinds of zero error : The zero error is of the following *two* kinds :

(i) Positive zero error, and (ii) Negative zero error.

(i) Positive zero error : If on bringing the flat end *B* of the screw in contact with the stud *A*, the zero mark on the circular scale is ***below the base line*** of main scale, the zero error is said to be ***positive.*** Fig. 1.9 shows the position of two scales of a screw gauge with positive zero error. To find it, we note that division of the circular scale which coincides with the base line. This number when multiplied with the least count of the screw gauge, gives the value of positive zero error.

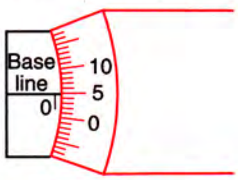

Fig. 1.9 Positive zero error

In Fig. 1.9, the 5th division of circular scale coincides with the base line. If the least count of the screw gauge is 0·001 cm, then zero error = + 5 × 0·001 cm = + 0·005 cm.

(ii) Negative zero error : If on bringing the flat end B of the screw in contact with the stud A, the zero mark on the circular scale is ***above the base line*** of main scale, the zero error is said to be ***negative.*** Fig. 1.10 shows the position of two scales of a screw gauge with negative zero error. To find it, we note the division of the circular scale coinciding with the base line. This number is subtracted from the total number of divisions on the circular scale and is then multiplied with the least count of the screw gauge. This gives the value of *negative zero error.*

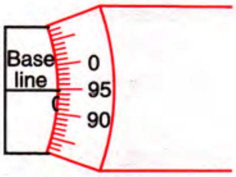

Fig. 1.10 Negative zero error

In Fig. 1.10, 95th division of circular scale coincides with the base line and total number of divisions on the circular scale are 100. If least count of the screw gauge is 0·001 cm, then zero error = – (100 – 95) × 0·001 cm = – 0·005 cm.

(d) *Correction due to zero error i.e., correct reading with a screw gauge having a zero error*

To find the correct reading, the zero error *with its sign* is subtracted from the observed reading. Thus,

Correct reading = observed reading – zero error (with sign) ....(1.7)

(e) *Measurement of diameter of a wire with a screw gauge*

Procedure :

(i) Find the least count and the zero error of the screw gauge.

(ii) Turn the ratchet anticlockwise so as to obtain a gap between the stud A and the flat end B. Place the wire in the gap between the stud A and the flat end B. Then turn the ratchet clockwise so as to hold the given wire gently between the stud A and the flat end B of the screw.

(iii) Note the main scale reading.

(iv) Note that division p of the circular scale which coincides with the base line of the main scale. This circular scale division p when multiplied by the least count, gives the circular scale reading *i.e.*,

Circular scale reading = p × L.C.

(v) Add the circular scale reading to the main scale reading to obtain the total reading (*i.e.*, the observed diameter of the wire).

(vi) Repeat it by keeping the wire in perpendicular direction. Take *two* more observations at different places of wire and record them in the table below.

Observation : Pitch of the screw = ... cm

Total number of divisions on circular scale = ...

Least counting screw gauge (L.C.)

$$= \frac{\text{Pitch}}{\text{Total number of divisions on circular scale}} = \text{........... cm}$$

Zero error = ...

S.No.	Main scale reading a (in cm)	Circular reading b = number of division of circular scale in line of bass line p × L.C. (in cm)	Observed diameter = $a + b$ (in cm)
1. (i) in one direction (ii) in ⊥ direction			
2. (i) (ii)			
3. (i) (ii)			

Mean observed diameter = ... cm

From the observed mean diameter, subtract the zero error (if any) with its sign to get the true diameter. Thus,

Observed diameter = main scale reading + (circular scale division p coinciding the base line of main scale × least count).
True diameter = observed diameter − zero error (with sign). ...... (1.8)

Example : Fig. 1.11 illustrates how to read a screw gauge.

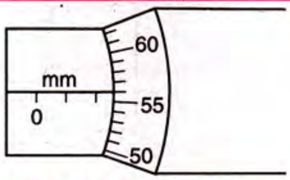

Fig. 1.11 Reading a screw gauge

In Fig. 1.11,

The pitch of the screw = 0·1 cm

The least count of the screw gauge = 0·001 cm.

Main scale reading = 2 mm = 0·2 cm.

56th division of circular scale coincides with the base line *i.e.*, $p = 56$

∴ Circular scale reading $= 56 \times 0{\cdot}001$ cm
$= 0{\cdot}056$ cm.

Hence, observed reading $= 0{\cdot}2$ cm + $0{\cdot}056$ cm.
$= 0{\cdot}256$ cm.

If the screw gauge is free from zero error, then true reading = 0·256 cm.

(f) *Backlash error*

Sometimes due to wear and tear of threads of screw, it is observed that on reversing the direction of rotation of the thimble, the tip of the screw does not start moving in the opposite direction *at once*, but it remains stationary for a part of rotation. This causes error in the observation which is called the *backlash error*.

To avoid the backlash error, while taking the measurements, the screw should be rotated in one direction only. If it is required to change the direction of rotation of the screw, do not change the direction of rotation at once. Move the screw still further, stop there for a while and then rotate it in the reverse direction.

Note : From above discussion, we find that a metre rule (L.C. = 1 mm), vernier callipers (L.C. = 0·1 mm) and screw gauge (L.C. = 0·01 mm) have decreasing least count which leads to the increase in accuracy.

EXAMPLES

1. In an instrument, there are 25 divisions on the vernier scale which have length of 24 divisions of the main scale. 1 cm on main scale is divided in 20 equal parts. Find the least count.

The value of one main scale division $x = \frac{1}{20}$ cm

The number of divisions on vernier scale $n = 25$

∴ L.C. of vernier

$$= \frac{\text{Value of one main scale division } (x)}{\text{Number of divisions on vernier scale } (n)}$$

$$= \frac{(1/20)\text{ cm}}{25} = \frac{1}{500}\text{cm} = \mathbf{0{\cdot}002\ cm.}$$

2. Fig. 1.12 given below shows the two scales of a vernier callipers. Find : (i) the least count of the vernier, and (ii) the reading shown in the diagram.

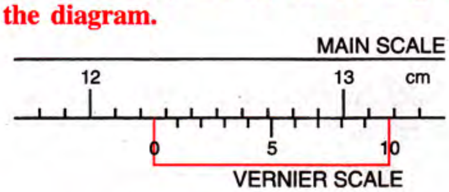

Fig. 1.12

(i) There are 10 divisions in 1 cm on the main scale.

∴ The value of one main scale division $x = \frac{1}{10}$ cm
$= 0{\cdot}1$cm.

The number of divisions on vernier scale $n = 10$.

∴ The least count of vernier $= \frac{x}{n} = \frac{0{\cdot}1\text{cm}}{10} = \mathbf{0{\cdot}01\ cm.}$

(ii) Main scale reading = 12·2 cm.

Since 7th division of vernier scale coincides with the main scale division, so, $p = 7$

∴ Vernier scale reading $= 7 \times 0{\cdot}01$ cm $= 0{\cdot}07$ cm.

Total reading = main scale reading + vernier scale reading
$= 12{\cdot}2 + 0{\cdot}07 =$ **12·27 cm**

3. The least count of a vernier callipers is 0·01 cm and its zero error is + 0·02 cm. While measuring the length of a rod, the main scale reading is 4·8 cm and sixth division on vernier scale is in line with a marking on the main scale. Calculate the length of the rod.

Given, L.C. = 0·01cm, zero error = + 0·02 cm, main scale reading = 4·8 cm, and number of

vernier division coinciding with the main scale division is 6, so, $p = 6$

Length of the rod = observed reading – zero error

= [main scale reading + (coinciding vernier division × L.C.)] – zero error.

$= [(4{\cdot}8 \text{ cm}) + (6 \times 0{\cdot}01 \text{ cm})] + (-\ 0{\cdot}02 \text{ cm})$

$= (4{\cdot}8 \text{ cm} + 0{\cdot}06 \text{ cm}) - (+\ 0{\cdot}02 \text{ cm})$

$= 4{\cdot}86 \text{ cm} - 0{\cdot}02 \text{ cm} =$ **4·84 cm.**

4. The circular head of a screw gauge is divided into 50 divisions and the screw moves 1 mm ahead in two revolutions of the circular head. Find its (a) pitch and (b) least count.

Given, number of divisions on circular head = 50, and distance moved in two revolutions = 1 mm

(a) Pitch = distance moved ahead in 1 revolution

$= \frac{1 \text{ mm}}{2} = 0{\cdot}5 \text{ mm} =$ **0·05 cm**

(b) Least count $= \dfrac{\text{Pitch}}{\text{Number of divisions on circular head}}$

$\therefore \quad \text{L.C.} = \frac{0{\cdot}05 \text{ cm}}{50} =$ **0·001 cm.**

5. The pitch of a screw gauge is 1 mm and there are 100 divisions on the circular head. While measuring the diameter of a wire, the main scale reads 3 mm and the 55th division is in line with the base line. Find the diameter of the wire. Assume that the screw gauge is free from zero error.

Given, pitch = 1 mm, number of divisions on circular head = 100, main scale reading = 3 mm, number of division of circular head in line with base line is 55, so, $p = 55$.

Least count $= \dfrac{\text{Pitch}}{\text{Number of divisions on circular head}}$

$= \frac{1 \text{ mm}}{100} = 0{\cdot}01 \text{ mm}$

Circular scale reading $= p \times \text{L.C.} = 55 \times 0{\cdot}01 \text{ mm}$

Diameter of the wire = main scale reading + circular scale reading

$= 3 \text{ mm} + (55 \times 0{\cdot}01 \text{ mm})$

$= 3 \text{ mm} + 0{\cdot}55 \text{ mm}$

= **3·55 mm** or **0·355 cm.**

6. In Fig. 1.13, the pitch of the screw is 1 mm. Find : (i) the least count of screw gauge and (ii) the reading represented in the diagram.

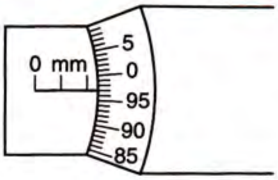

Fig. 1.13

(i) Given, pitch of the screw = 1 mm

Number of divisions on the circular scale = 100

∴ L.C. of the screw gauge

$= \dfrac{\text{Pitch}}{\text{Number of divisions on circular scale}} = \dfrac{1 \text{ mm}}{100}$

= **0·01 mm** or **0·001 cm.**

(ii) Main scale reading = 2 mm = 0·2 cm

Since 97th division of head scale coincides with base line, *i.e.*, $p = 97$

∴ Circular scale reading $= p \times \text{L.C.}$

$= 97 \times 0{\cdot}001 \text{cm} = 0{\cdot}097 \text{ cm}$

Total reading = main scale reading + circular scale reading

$= 0{\cdot}2 \text{ cm} + 0{\cdot}097 \text{ cm} =$ **0·297 cm.**

7. A boy measures the length of a piece of pencil by metre rule, vernier callipers and screw gauge to be 1·2 cm, 1·24 cm and 1·243 cm respectively. State (a) the least count of each measuring instrument, (b) the accuracy in each measurement.

(a) Least count of metre rule = **0·1 cm**

Least count of vernier callipers = **0·01 cm**

Least count of screw gauge = **0·001 cm**

(b) Accuracy in 1·2 cm = **0·1 cm**

Accuracy in 1·24 cm = **0·01 cm**

Accuracy in 1·243 cm = **0·001 cm**

EXERCISE 1 (B)

1. Explain the meaning of the term 'least count of an instrument' by taking a suitable example.
2. A boy makes a ruler with graduations in cm on it (*i.e.*, 100 divisions in 1 m). To what accuracy this ruler can measure ? How can this accuracy be increased ?
3. A boy measures the length of a pencil and expresses it to be 2·6 cm. What is the accuracy

of his measurement ? Can he write it as 2·60 cm ?

4. Define least count of a vernier callipers. How do you determine it ?
5. Define the term 'Vernier constant'.
6. When is a vernier callipers said to be free from zero error ?
7. What is meant by zero error of a vernier callipers ? How is it determined ? Draw neat diagrams to explain it. How is it taken in account to get the correct measurement ?
8. A vernier callipers has a zero error + 0·06 cm. Draw a neat labelled diagram to represent it.
9. Draw a neat labelled diagram of a vernier callipers. Name its main parts and state their functions.
10. State *three* uses of a vernier callipers.
11. Name the *two* scales of a vernier callipers and explain, how is it used to measure a length correct up to 0·01 cm.
12. Describe in steps, how would you use a vernier callipers to measure the length of a small rod ?
13. Name the part of the vernier callipers which is used to measure the following :
    (a) external diameter of a tube,
    (b) internal diameter of a mug,
    (c) depth of a small bottle,
    (d) thickness of a pencil.
14. Explain the terms (i) pitch, and (ii) least count of a screw gauge. How are they determined ?
15. How can the least count of a screw gauge be decreased ?
16. Draw a neat and labelled diagram of a screw gauge. Name its main parts and state their functions.
17. State *one* use of a screw gauge.
18. State the purpose of ratchet in a screw gauge.
19. What do you mean by zero error of a screw gauge ? How is it accounted for ?
20. A screw gauge has a least count 0·001 cm and zero error + 0·007 cm. Draw a neat diagram to represent it.
21. What is backlash error ? Why is it caused ? How is it avoided ?
22. Describe the procedure to measure the diameter of a wire with the help of a screw gauge.
23. Name the instrument which can measure accurately the following :
    (a) the diameter of a needle,
    (b) the thickness of a paper,
    (c) the internal diameter of the neck of a water bottle,
    (d) the diameter of a pencil.

    Ans. (a) screw gauge (b) screw gauge (c) vernier callipers (d) screw gauge.
24. Which of the following measures a small length to a high accuracy : metre rule, vernier callipers, screw gauge ? **Ans.** screw gauge
25. Name the instrument which has the least count : (a) 0·1 mm (b) 1 mm (c) 0·01 mm.

    Ans. (a) vernier callipers (b) metre rule (c) screw gauge.

Multiple choice type :

1. The least count of a vernier callipers is :
   (a) 1 cm (b) 0·001 cm
   (c) 0·1 cm (d) 0·01 cm

   Ans. (c) 0·01 cm
2. A microscope has its main scale with 20 divisions in 1 cm and vernier scale with 25 divisions, the length of which is equal to the length of 24 divisions of main scale. The least count of microscope is :
   (a) 0·002 cm (b) 0·001 cm
   (c) 0·02 cm (d) 0·01 cm

   Ans. (a) 0·002 cm
3. The diameter of a thin wire can be measured by :
   (a) a vernier callipers (b) a metre rule
   (c) a screw gauge (d) none of these.

   Ans. (c) a screw gauge

Numericals :

1. A stop watch has 10 divisions graduated between the 0 and 5 s marks. What is its least count ? **Ans.** 0·5 s.
2. A vernier has 10 divisions and they are equal to 9 divisions of main scale in length. If the main scale is calibrated in mm, what is its least count ? **Ans.** 0·01 cm.
3. A microsocpe is provided with a main scale graduated with 20 divisions in 1 cm and a vernier scale with 50 divisions on it of length same as of 49 divisions of main scale. Find the least count of the microscope. **Ans.** 0·001 cm
4. A boy uses a vernier callipers to measure the thickness of his pencil. He measures it to be 1·4 mm. If the zero error of vernier callipers is + 0·02 cm, what is the correct thickness of pencil ? **Ans.** 1·2 mm

5. A vernier callipers has its main scale graduated in mm and 10 divisions on its vernier scale are equal in length to 9 mm. When the two jaws are in contact, the zero of vernier scale is ahead of zero of main scale and 3rd division of vernier scale coincides with a main scale division. Find : (i) the least count and (ii) the zero error of the vernier callipers.

Ans. (i) 0·01 cm (ii) + 0·03 cm

6. The main scale of a vernier callipers is calibrated in mm and 19 divisions of main scale are equal in length to 20 divisions of vernier scale. In measuring the diameter of a cylinder by this instrument, the main scale reads 35 divisions and 4th division of vernier scale coincides with a main scale division. Find : (i) least count and (ii) radius of cylinder.

Ans. (i) 0·005 cm, (ii) 1·76 cm

7. In a vernier callipers, there are 10 divisions on the vernier scale and 1 cm on the main scale is divided in 10 parts. While measuring a length, the zero of the vernier lies just ahead of 1·8 cm mark and 4th division of vernier coincides with a main scale division.

(a) Find the length.

(b) If zero error of vernier callipers is – 0·02 cm, what is the correct length ?

Ans. (a) 1·84 cm, (b) 1·86 cm

8. While measuring the length of a rod with a vernier callipers, Fig. 1.14 below shows the position of its scales. What is the length of the rod ?

Fig. 1.14 **Ans.** 3·36 cm

9. The pitch of a screw gauge is 0·5 mm and the head scale is divided in 100 parts. What is the least count of screw gauge ?

Ans. 0·005 mm or 0·0005 cm.

10. The thimble of a screw gauge has 50 divisions. The spindle advances 1 mm when the screw is turned through two revolutions.

(i) What is the pitch of screw gauge ?

(ii) What is the least count of the screw gauge?

Ans. (i) 0·5 mm (ii) 0·01 mm.

11. The pitch of a screw gauge is 1 mm and its circular scale has 100 divisions. In measurement of the diameter of a wire, the main scale reads 2 mm and 45th mark on circular scale coincides with the base line. Find :

(i) the least count, and

(ii) the diameter of the wire.

Ans. (i) 0·001cm (ii) 0·245 cm.

12. When a screw gauge of least count 0·01 mm is used to measure the diameter of a wire, the reading on the sleeve is found to be 1 mm and the reading on the thimble is found to be 27 divisions. (i) What is the diameter of the wire in cm ? (ii) If the zero error is + 0·005 cm, what is the correct diameter ?

Ans. (i) 0·127 cm (ii) 0·122 cm.

13. A screw gauge has 50 divisions on its circular scale and its screw moves by 1 mm on turning it by two rotations. When the flat end of the screw is in contact with the stud, the zero of circular scale lies below the base line and 4^{th} division of circular scale is in line with the base line. Find : (i) the pitch, (ii) the least count and (iii) the zero error, of the screw gauge.

Ans. (i) 0·5 mm (ii) 0·01 mm (iii) + 0·04 mm

14. Fig. 1.15 below shows the reading obtained while measuring the diameter of a wire with a screw gauge. The screw advances by 1 division on main scale when circular head is rotated once.

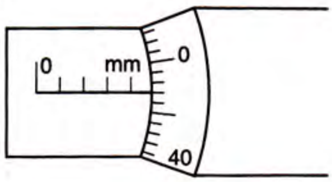

Fig 1.15

Find : (i) pitch of the screw gauge,

(ii) least count of the screw gauge, and

(iii) the diameter of the wire.

Ans. (i) 1 mm (ii) 0·02 mm (iii) 4·94 mm.

15. A screw has a pitch equal to 0·5 mm. What should be the number of divisions on its head so as to read correct up to 0·001 mm with its help ? **Ans.** 500

(C) MEASUREMENT OF TIME AND SIMPLE PENDULUM

1.14 MEASUREMENT OF TIME

In offices and home, we commonly use a *pendulum clock* to note time which is based on the periodic oscillations of a pendulum. Here we shall study the principle of a simple pendulum.

Simple pendulum

A simple pendulum is a heavy point mass (known as bob) suspended from a rigid support by a massless and inextensible string. This is an ideal case because we cannot have a heavy mass having the size of a point and a string which has no mass. Fig. 1.16 shows a simple pendulum. Here a heavy solid (iron or brass) ball is suspended by a light, but strong thread from a rigid support. The ball is called the bob. In Fig. 1.16, the rest (or mean) position of bob is *O*.

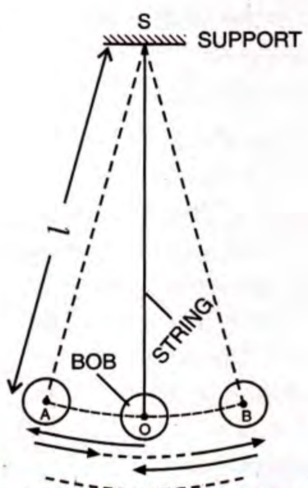

Fig. 1.16 A simple pendulum

When the bob from its mean position *O* is pulled to one side and then released, the pendulum is set in motion and the bob moves alternately on either side of its mean position.

Note : The pendulum used in a clock is not a simple pendulum, but it is a ***compound pendulum*** (*i.e.*, a body capable of oscillating about a *horizontal axis passing through it).*

(i) *Some terms related to simple pendulum*

Oscillation : *One complete to and fro motion of the bob of pendulum is called one oscillation.* For example in a simple pendulum shown in Fig. 1.16, the rest (or mean) position of bob is *O*, while its extreme positions on left and right sides are *A* and *B* respectively. One oscillation is the motion of the bob from *O* to *A, A* to *B* and then back from *B* to *O* as shown by arrows in Fig. 1.16. The motion of bob from *A* to *B* and then back from *B* to *A* also represent one oscillation.

Period of oscillation or time period : *This is the time taken to complete one oscillation.* It is denoted by the symbol *T*. Its unit is second (s).

Frequency of oscillation : *It is the number of oscillations made in one second.* It is denoted by the letter *f* or *n*. Its unit is per second (s^{-1}) or hertz (Hz).

Relationship between time period and frequency: If *T* is the time period of a simple pendulum, then

In time *T* second, the number of oscillation is 1.

∴ In time 1 second, the number of oscillations will be $\frac{1}{T}$ which is the frequency *f*.

i.e., $$\boxed{f = \frac{1}{T} \quad \text{or} \quad T = \frac{1}{f}} \qquad .....(1.18)$$

Amplitude : *The maximum displacement of the bob from its mean position on either side, is called the amplitude of oscillation*. In Fig. 1.16, the amplitude is *OA* or *OB*. It is denoted by the letter *a* or *A* and is measured in metre (m).

Effective length of a pendulum : *It is the distance of the point of oscillation O (i.e., the centre of gravity of the bob) from the point of suspension S.* In Fig. 1.16 it is shown by *l*.

(ii) *Measurement of time period of a simple pendulum*

To measure the time period of a simple pendulum, the bob is slightly displaced from its rest (mean) position *O* and is then released. It begins to move to and fro about its mean position *O* in a vertical plane along with the string. The time *t* for 20 complete oscillations is measured with the help of a stop watch and then dividing *t* by 20, its time period *T* is calculated*.

* To find time period, the time for number of oscillations more than 1 is noted because the least count of stop watch is either 1 s or 0·5 s. It can not record the time period in fraction such as 1·2 s or 1·4 s and so on. It is made possible by noting the time *t* for 20 oscillations or more than it and then dividing *t* by the number of oscillations.

The experiment is then repeated for different lengths of the pendulum. The observations are recorded in the table given below.

Time period for pendulum of different lengths

S.No	Length l (in cm)	Time for 20 oscillations t (in s)	Time period $T = \frac{t}{20}$ (in s)	$\frac{l}{T^2}$ (in cm s^{-2})
1	25	20	1·0	25
2	36	24	1·2	25
3	49	28	1·4	25
4	64	32	1·6	25
5	81	36	1·8	25
6	100	40	2·0	25

From the above observations 1 and 6, it can be noted that if the length of a pendulum is made four times, the period of oscillation gets doubled *i.e.*, now it takes twice the time for one complete to and fro motion. Thus time period T is directly proportional to the square root of length l of the pendulum ($T \propto \sqrt{l}$) or the square of time period T^2 is directly proportional to the length l of the pendulum (*i.e.*, $T^2 \propto l$) or l/T^2 is a constant.

(iii) *Graph showing the variation of square of time period (T^2) with the length (l) of a pendulum*

If a graph is plotted for the square of time period (T^2) taken on Y-axis against the length l taken on X-axis, it comes out to be a straight line inclined to the l-axix as shown in Fig. 1.17. This shows that T^2 is directly proportional to l.

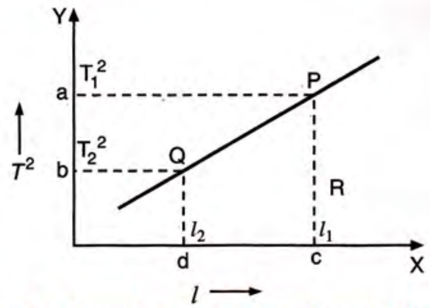

Fig. 1.17 Graph showing variation of T^2 with l

(iv) *Slope of T^2 vs l graph*

The slope of the straight line obtained in the T^2 vs l graph as shown in Fig. 1.17 can be obtained by taking two points P and Q on the straight line and drawing normals from these points on the X and Y axes. Then note the value of T^2 say T_1^2 and T_2^2 at a and b respectively, and also the value of l say l_1 and l_2 respectively at c and d. Then

$$Slope = \frac{PR}{QR} = \frac{ab}{cd} = \frac{T_1^2 - T_2^2}{l_1 - l_2}$$

This slope is found to be a constant at a place and is equal to $\frac{4\pi^2}{g}$ where g is the acceleration due to gravity at that place. Thus g can be determined at a place from these measurements by using the following relation :

$$g = \frac{4\pi^2}{\text{Slope of } T^2 \text{ vs } l \text{ graph}} \quad ....(1.9)$$

(v) *Factors affecting the time period of a simple pendulum*

From experiments on simple pendulum, it is observed that

(i) *The time period of oscillation is directly proportional to the square root of its effective length* *i.e.*, $T \propto \sqrt{l}$ or in other words, the square of time period of oscillation (T^2) is directly proportional to its effective length *(l) i.e.*, $T^2 \propto l$.

A pendulum clock has a compound pendulum made up of a metal like brass (or steel). Due to seasonal change of temperature, the effective length of pendulum changes, due to which the clock goes fast in winter and slow in summer. In winter due to contraction, the effective length of the pendulum gets shortened, and so its time period is decreased and the pendulum completes more oscillations in a given time *i.e.*, the clock goes fast. But in summer because of expansion *i.e.*, increase in the effective length of pendulum, its time period is increased and it completes less number of oscillations in a given time *i.e.*, the clock goes slow.

Similarly, while swinging, if we *stand* on the swing, the time period of swing decreases (*i.e.*, the swing moves faster). This is because when we stand, the centre of gravity rises, so the effective length of the swing decreases due to which its time period decreases.

(ii) *The time period of oscillation is inversely proportional to the square root of acceleration due to gravity i.e.*, $T \propto \frac{1}{\sqrt{g}}$

For this reason, a pendulum clock goes slow (*i.e.*, the time period of oscillation increases) when

it is taken to mountains or to mines due to decrease in the value of g.*

(iii) *The time period of oscillation does not depend on the mass or material of the body suspended (i.e., bob).* If we take two pendulums of equal lengths, but with bobs of different masses or different materials, their time periods will remain same.

(iv) *The time period of oscillation does not depend on the extent of swing on either side (i.e., on amplitude)* provided the swing is not too large.

(vi) *Expression for the time period of simple pendulum*

The time period of oscillation of the pendulum is given by the following relation :

$$T = 2\pi\sqrt{\frac{l}{g}}$$

* The value of acceleration due to gravity g decreases with altitude as well as with depth from the earth surface.

or $$\boxed{T^2 = 4\pi^2 \frac{l}{g}} \quad .....(1.10)$$

where T = time period,

l = effective length of pendulum,

and g = acceleration due to gravity.

At a given place, since g is constant, the time period of a pendulum of given length is constant. This is why a pendulum can be used to measure the time.

(vii) *Seconds' pendulum*

The pendulum of a clock which we use to note time in our house, is a seconds' pendulum. It takes time 1 s in moving from one extreme to the other extreme, so its time period is 2 s. Thus, *a pendulum with a time period of oscillation equal to two seconds, is known as a seconds pendulum.* The effective length of the seconds' pendulum, at a place where $g = 9{\cdot}8$ m s^{-2} (the average value), is nearly 1 metre.

EXAMPLES

1. Calculate the length of a seconds' pendulum at a place where $g = 9{\cdot}8$ m s^{-2}.

For seconds' pendulum $T = 2{\cdot}0$ s, $g = 9{\cdot}8$ m s^{-2}.

From the relation $T = 2\pi\sqrt{\frac{l}{g}}$,

length of pendulum, $l = \frac{gT^2}{4\pi^2}$

$\therefore \quad l = \frac{9{\cdot}8 \times (2{\cdot}0)^2}{4 \times (3{\cdot}14)^2} = \mathbf{0{\cdot}994\ m}$

2. Compare the time periods of a simple pendulum at places where g is 9·8 m s^{-2} and 4·36 m s^{-2} respectively.

Given : $g_1 = 9{\cdot}8$ m s^{-2}, $g_2 = 4{\cdot}36$ m s^{-2}

Since $T \propto \frac{1}{\sqrt{g}} \quad \therefore \frac{T_1}{T_2} = \sqrt{\frac{g_2}{g_1}}$

or $\frac{T_1}{T_2} = \sqrt{\frac{4{\cdot}36}{9{\cdot}8}} = \frac{1}{1{\cdot}5} = \frac{2}{3}$

i.e., $T_1 : T_2$ = **2 : 3** (or **0·667 : 1**)

3. Compare the time periods of two simple pendulums of length 1 m and 16 m at a place.

Given : l_1 = 1 m and l_2 = 16 m

Since $T \propto \sqrt{l} \quad \therefore \frac{T_1}{T_2} = \sqrt{\frac{l_1}{l_2}}$

$\therefore \quad \frac{T_1}{T_2} = \sqrt{\frac{1}{16}} = \frac{1}{4}$ *i.e.*, $T_1 : T_2$ = **1 : 4**

4. (a) A simple pendulum is made by suspending a bob of mass 500 g by a string of length 1 m. Calculate its time period at a place where $g = 10$ m s^{-2}.

(b) How will the time period in part (a) be affected if bob of mass 100 g is used, keeping the length of string unchanged ?

(a) Given : l = 1 m, g = 10 m s^{-2}

Time period $T = 2\pi\sqrt{\frac{l}{g}} = 2 \times 3{\cdot}14 \times \sqrt{\frac{1}{10}}$

= **1·99 s**

(b) On changing the bob by other bob of different mass, the time period will **remain unaffected** because it does not depend on the mass of bob.

EXERCISE 1 (C)

1. What is a simple pendulum ? Is the pendulum used in a pendulum clock simple pendulum ? Give reason to your answer.

2. Define the terms : (i) oscillation, (ii) amplitude, (iii) frequency, and (iv) time period as related to a simple pendulum.

3. Draw a neat diagram of a simple pendulum. Show on it the effective length of the pendulum and its one oscillation.

4. Name *two* factors on which the time period of a simple pendulum depends. Write the relation for the time period in terms of the above named factors.

5. Name *two* factors on which the time period of a simple pendulum does not depend.

6. How is the time period of a simple pendulum affected, if at all, in the following situations :
   (a) the length is made four times,
   (b) the acceleration due to gravity is reduced to one-fourth,

   Ans. (a) doubled, (b) doubled,

7. How are the time period T and frequency f of an oscillation of a simple pendulum related ?

   Ans. $f = \frac{1}{T}$

8. How do you measure the time period of a given pendulum ? Why do you note the time for more than one oscillation ?

9. How does the time period (T) of a simple pendulum depends on its length (l) ? Draw a graph showing the variation of T^2 with l. How will you use this graph to determine the value of g (acceleration due to gravity) ?

10. Two simple pendulums A and B have equal length, but their bobs weigh 50 gf and 100 gf respectively. What would be the ratio of their time periods ? Give reason for your answer.

    Ans. 1 : 1 ; **Reason :** Time period does not depend on the weight of the bob.

11. Two simple pendulums A and B have length 1·0 m and 4·0 m respectively at a certain place. Which pendulum will make more oscillations in 1 minute ? Explain your answer.

    Ans. A. The reason is that $T \propto \sqrt{l}$ $\therefore$ time period of B is more (twice) than that of A. Hence A will make more oscillations (twice) in a given time, than B.

12. State how does the time period of a simple pendulum depend on (a) length of pendulum, (b) mass of bob, (c) amplitude of oscillation and (d) acceleration due to gravity.

13. What is a seconds' pendulum ?

14. State the numerical value of the frequency of oscillation of a seconds' pendulum. Does it depend on the amplitude of oscillation ?

    Ans. 0·5 s^{-1}, No.

Multiple choice type :

1. The length of a simple pendulum is made one-fourth. Its time period becomes :
   (a) four times (b) one-fourth
   (c) double (d) half.

   Ans. (d) half

2. The time period of a pendulum clock is :
   (a) 1 s (b) 2 s
   (c) 1 min (d) 12 h

   Ans. (b) 2 s

3. The length of a seconds' pendulum is nearly :
   (a) 0·5 m (b) 9·8 m
   (c) 1·0 m (d) 2·0 m.

   Ans. (c) 1·0 m

Numericals :

1. A simple pendulum completes 40 oscillations in one minute. Find its (a) frequency, (b) time period.

   Ans. (a) 0·67 s^{-1} (b) 1·5 s

2. The time period of a simple pendulum is 2 s. What is its frequency ? What name is given to such a pendulum ?

   Ans. 0·5 s^{-1}, seconds' pendulum

3. A seconds' pendulum is taken to a place where acceleration due to gravity falls to one-fourth. How is the time period of the pendulum affected, if at all ? Give reason. What will be its new time period ?

   Ans. The time period increases (it is doubled) because $T \propto \frac{1}{\sqrt{g}}$. Its new time period will be 4 s.

4. Find the length of a seconds' pendulum at a place where $g = 10 \text{ m s}^{-2}$ (Take $\pi = 3{\cdot}14$). **Ans.** 1·0142 m

5. Compare the time periods of two pendulums of length 1 m and 9 m. **Ans.** 1 : 3

6. A pendulum completes 2 oscillations in 5 s. (a) What is its time period ? (b) If $g = 9{\cdot}8 \text{ m s}^{-2}$, find its length. **Ans.** (a) 2·5 s, (b) 1·55 m

7. The time periods of two simple pendulums at a place are in ratio 2 : 1. What will be the ratio of their length ? **Ans.** 4 : 1

8. It takes 0·2 s for a pendulum bob to move from mean position to one end. What is the time period of pendulum ? **Ans.** 0·8 s

9. How much time does the bob of a seconds' pendulum take to move from one extreme of its oscillation to the other extreme ? **Ans.** 1 s

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2 MOTION IN ONE DIMENSION

Syllabus :

Scalar and vector quantities, distance, speed, velocity, acceleration; graphs of distance-time and speed-time., Equations of uniformly accelerated motion with derivations.

Scope – Examples of scalar and vector quantities only, rest and motion in one dimension, distance and displacement, speed and velocity; acceleration and retardation; distance-time and velocity-time graphs; meaning of slope of the graphs. (Non-uniform acceleration excluded). Equations to be derived : $v = u + at$; $S = ut + \frac{1}{2}at^2$; $S = \frac{1}{2}(u + v)t$; $v^2 = u^2 + 2aS$ (equation for S_n^{th} is not included), Simple numerical problems.

(A) SOME TERMS RELATED TO MOTION

2.1 SCALAR AND VECTOR QUANTITIES

The quantities which we can measure are called the physical quantities. The physical quantities are classified into the following *two* broad categories:

(1) Scalar quantities or scalars, and (2) Vector quantities or vectors.

(1) *Scalar quantities or scalars* : *These are the physical quantities which are expressed only by their magnitude.* For example, if we say that the mass of a body is 5·0 kg, it has a complete meaning and we are completely expressing the mass of the body. Thus, we need the following two parameters to express a scalar quantity completely :

(i) Unit in which the quantity is being measured, and

(ii) The numerical value of the quantity.

Remember that if the scalar is a pure number (like π, e^2, etc.), it will have no unit.

Examples : Mass, length, time, distance, density, volume, speed, temperature, potential (gravitational, magnetic and electric), work, energy, power, pressure, quantity of heat, specific heat, charge, electric power, resistance, density, mechanical advantage, frequency, angle etc.

Scalar quantities can be added, subtracted, multiplied and divided by the simple arithmetic methods. Scalar quantity is symbolically written by its English letter. For example, mass is represented by the letter m, time by t and speed by v.

(2) *Vector quantities or vectors* : *These physical quantities require the magnitude as well as the direction to express them, then only their meaning is complete.* For example, if we say that "displace a particle from a point by 5 m", the first question that will arise, will be "in which direction"? Obviously, by saying that the displacement is 5 m, its meaning is incomplete. But if we say that displace the particle from that point by 5 metre towards east (or in any other direction), it has a complete meaning. Thus, we require the following three meters to express a vector quantity completely :

(i) Unit,

(ii) Numerical value of the quantity and

(iii) Direction.

Examples : Displacement, velocity, acceleration, momentum, force, moment of a force (or torque), impulse, weight, temperature gradient, electric field, magnetic field, dipole moment, *etc*.

The numerical value of a vector quantity alongwith its unit gives us the magnitude of that quantity. It is always positive. The negative sign with a vector quantity implies the reverse (or opposite) direction. Vector quantities follow different algebra for their addition, subtraction and multiplication. A vector quantity is generally written by its English letter bearing an arrow on it or by the bold English letter. For example, velocity is written as $\vec{v}$ or $\boldsymbol{v}$, acceleration by $\vec{a}$ or $\boldsymbol{a}$, force by $\vec{F}$ or $\boldsymbol{F}$. Obviously the forces $\vec{F}$ and $-\vec{F}$ are in opposite directions.

2.2 REST AND MOTION

Every object in the universe is in motion. Everyday we see bodies moving around us e.g. birds flying, cars and buses moving, people

walking, insects crawling, animals running etc. Our earth also moves around the sun so every thing on it is in a state of motion. The sun and stars are moving around the centre of their galaxy and the galaxies too are not at rest.

Although nothing is at rest, but we often say that a stone lying on the ground is at rest because the stone does not change its position with respect to us. Similarly, if we are sitting on a railway platform and look at a tree nearby, we say that the tree is at rest because it does not change its position *with respect to us*. But when we see a train leaving the station, we say that the train is in motion because it is continuously changing its position *with respect to us*. Thus,

A body is said to be at rest if it does not change its position with respect to its immediate surroundings, while a body is said to be in motion if it changes its position with respect to its immediate surroundings.

For a moving body, if the distance travelled in a certain time interval is much large as compared to the size of the body, the body can be assumed to be a point particle. In this chapter, we shall study the description of motion of a body assuming it to be a point particle.

One dimensional motion : *When a body moves along a straight line path, its motion is said to be one dimensional motion.* It is also called motion in a straight line or rectilinear motion. For example, the motion of a train on a straight track, a stone falling down vertically, a car moving on a long and straight road etc., are one dimensional (or rectilinear) motions. In such a motion, there is no movement of the body in lateral direction (*i.e.*, no sideways motion).

If a body moves on a plane along a curved path, its motion is two dimensional and if it moves in space, its motion is three dimensional. In this chapter, we shall consider only the one dimensional motion.

Representation of one dimensional motion : The path of one dimensional motion can be represented by a straight line parallel to the X-axis if X-axis is taken in the direction of motion. Each point on the straight line represents the position of particle at different instants. The position of particle at any instant t is expressed by specifying the x coordinate at that instant. As the particle moves, its x coordinate will change with time t.

Example : The position of a pebble measured from its starting point, falling freely and vertically downwards at different instants is given in the table below :

Time t (in s)	0	1	2	3	4
Position x (in m)	0	5	20	45	80

The motion of the pebble can be represented by choosing a proper scale for x on a straight line along X-axis as shown in Fig. 2.1. Here X-axis represents the vertically downward direction.

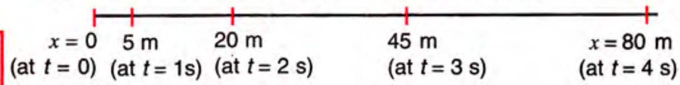

Fig. 2.1 Representation of one-dimensional motion

2.3 DISTANCE AND DISPLACEMENT

Consider a body moving from a point A to a point B along the path shown in Fig. 2.2. Then total length of path from A to B is called the *distance* moved by the body, while the length of straight line AB in direction from A to B (shown by the dotted line in Fig. 2.2) is called the *displacement* of the body.

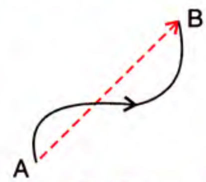

Fig. 2.2 Motion of a body from A to B

Distance

The total length of path through which a body moves, is called the distance travelled by it. The distance travelled by a body depends on the path followed by the body.

It is a **scalar quantity**. It is generally represented by the letter S.

Unit : The S.I. unit of distance is metre (m) and C.G.S. unit is centimetre (cm).

Displacement

The shortest distance from the initial to the final position of the body, is the magnitude of displacement and its direction is from the initial position to the final position.

It is a **vector quantity**. It is represented by the symbol $\vec{S}$.

Unit : The S.I. unit of displacement is metre (m) and C.G.S. unit is centimetre (cm).

Representation of displacement : The displacement being a vector, is represented by a straight line with an arrow, using a convenient scale. The tip of arrow on the straight line represents the direction of displacement, while the length of the straight line on proper scale represents its magnitude.

Example: In Fig. 2.3, the vector $\overrightarrow{PQ}$ represents 40 m displacement in east direction with scale 1 cm = 10 m (displacement). Here origin P is the initial position and terminus Q is the final position of the body

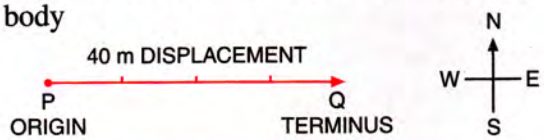

Fig. 2.3 Representation of displacement

Distinction between distance and displacement

(1) ***The magnitude of displacement is either equal to or less than the distance.*** If motion is along a fixed direction, the magnitude of displacement is equal to that of distance, but if motion is along a curve or any zig-zag path, the magnitude of displacement is always less than that of distance. *The magnitude of displacement can never be greater than the distance travelled by the body.*

Examples: **(i)** In Fig. 2.2, the body moves from A to B along a curved path. The distance travelled by the body is equal to the length of the curved path AB, but the displacement of the body is along the straight line AB shown by the dotted arrow. Obviously the magnitude of displacement is less than the distance.

(ii) In Fig. 2.4, a boy travels 4 km towards east and then 3 km towards north. The total distance travelled by the boy is $OA + AB$ = 4 km + 3 km = 7 km, but the displacement of the boy is OB = 5 km in direction $\overrightarrow{OB}$ *i.e.*, 36·9° due north from east.

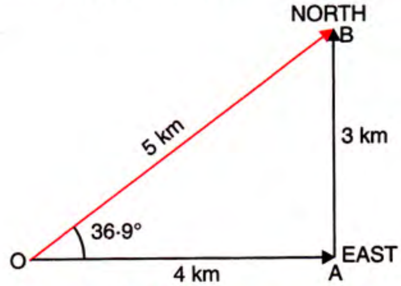

Fig. 2.4 Displacement as a vector

Thus, the magnitude of displacement is the length of the straight line between the final and initial positions.

(2) The distance is the length of path travelled by the body so it is always positive, but displacement is the shortest length in direction from initial position to the final position so it can be positive or negative depending on its direction.

(3) ***The displacement can be zero even if the distance is not zero.*** If a body, after travelling, comes back to its starting point, the displacement is zero but the distance travelled is not zero.

Examples: **(i)** When a body is thrown vertically upwards from a point A on the ground, after some time it comes back to the same point A, then the displacement of the body is zero, but the distance travelled by the body is not zero (it is $2h$ if h is the maximum height attained by the body).

(ii) A body moving in a circular path when reaches its original position after one round, then the displacement at the end of one round is zero, but the distance travelled by it is equal to the circumference of the circular path (= $2\pi r$ if r is the radius of the circular path).

Distinction between distance and displacement

Distance	Displacement
1. It is the length of the path traversed by the object in a certain time.	1. It is the distance travelled by the object in a specified direction in a certain time (*i.e.*, it is the shortest distance between the final and initial positions).
2. It is a scalar quantity *i.e.*, it has only the magnitude.	2. It is a vector quantity *i.e.*, it has both the magnitude and direction.
3. It depends on the path followed by the object.	3. It does not depend on the path followed by the object.
4. It is always positive.	4. It can be positive or negative depending on its direction.
5. It can be more than or equal to the magnitude of displacement.	5. Its magnitude can be less than or equal to the distance, but can never be greater than the distance.
6. It may not be zero even if displacement is zero, but it can not be zero if displacement is not zero.	6. It is zero if distance is zero, but it can be zero even if distance is not zero.

2.4 SPEED AND VELOCITY

For a moving body, speed is the quantity by which we know how fast the body is moving, while velocity is the quantity by which we know the speed of the body as well as its direction of motion. By speed we do not know the direction of motion of the body.

(1) *Speed*

The speed of a body is the rate of change of distance with time. Numerically it is the distance travelled by the body in 1 s.

It is a **scalar quantity.** It is generally represented by the letter u or v.

If a body travels a distance S in time t, then its speed v is

$$\boxed{\text{Speed } v = \frac{\text{Distance } S}{\text{Time } t}} \qquad ...(2.1)$$

Unit : Unit of speed = $\dfrac{\text{Unit of distance}}{\text{Unit of time}}$

Since S.I. unit of distance is metre (m) and of time is second (s), so the S.I. unit of speed is metre per second (m s^{-1}) and its C.G.S. unit is centimetre per second (cm s^{-1}).

Uniform speed : *A body is said to be moving with uniform speed if it covers equal distances in equal intervals of time throughout its motion.*

Example : The motion of a ball on a frictionless plane surface is with uniform speed.

Knowing the uniform speed of a body, we can calculate the distance moved by the body in a certain interval of time. If a body moves with a uniform speed v, the distance travelled by it in time t is given as :

$$\boxed{S = v\,t} \qquad ...(2.2)$$

Non-uniform or variable speed : *A body is said to be moving with non-uniform (or variable) speed if it covers unequal distances in equal intervals of time.*

Examples : The motion of a ball on a rough surface, the motion of a car in a crowded street, the motion of a vehicle leaving or approaching a destination etc., are with non-uniform speed.

In case of bodies moving with non-uniform speed, we specify their instantaneous speed and the average speed.

Instantaneous speed : When the speed of a body keeps on changing, its speed at any instant is measured by finding the ratio of the distance travelled in a *very short time interval* to the time interval. This speed is called the instantaneous speed. Thus,

$$\boxed{\text{Instantaneous speed} = \frac{\text{Distance travelled in a short time interval}}{\text{Time interval}}}$$

The speedometer of a vehicle measures the instantaneous speed.

Average speed : The ratio of the total distance travelled by the body to the total time of journey is called its average speed. Thus,

$$\boxed{\textit{Average speed} = \frac{\textit{Total distance travelled}}{\textit{Total time taken}}} \qquad ..(2.3)$$

In case of a body moving with uniform speed, the instantaneous speed and the average speed are equal (same as the uniform speed).

(2) *Velocity*

The velocity of a body is the distance travelled per second by the body in a specified direction.

Thus, *the rate of change of displacement of a body with time is called the velocity.* It is numerically equal to the displacement of the body in 1 s.

It is a **vector quantity** and is represented by the symbol $\vec{u}$ or $\vec{v}$. For velocity, both its magnitude and direction must be specified. Two bodies are said to be moving with same velocities if both of them move with the *same speed in the same direction.* On the other hand, if two bodies move with the *same speed but in different directions or with different speeds in the same direction*, they are said to be moving with different velocities.

Unit : The unit of velocity is same as the unit of speed *i.e.* the S.I. unit of velocity is metre per second (m s^{-1}) and the C.G.S. unit is centimetre per second (cm s^{-1}).

Uniform velocity : *If a body travels equal distances in a particular direction, in equal*

intervals of time, the body is said to be moving with a uniform velocity.

Example : The rain drops reach on earth's surface falling with uniform velocity*. A body, once started on a frictionless surface, moves with uniform velocity.

If a body moving with a uniform velocity $\vec{v}$, has displacement $\vec{S}$ in a time interval t then by defirition $\vec{v} = \vec{S}/t$.

$\therefore$ Displacement $\boxed{\vec{S} = \vec{v}\ t}$ ...... (2.4)

Non-uniform or variable velocity : The velocity of a body can be variable either due to change in its magnitude or in its direction or in both magnitude and direction. *If a body moves unequal distances in a particular direction in equal intervals of time or it moves equal distances in equal intervals of time, but its direction of motion does not remain the same, then the velocity of the body is said to be variable (or non-uniform).*

Examples : The motion of a freely falling body is with variable velocity because although the direction of motion of the body does not change, but the speed continuously increases. Similarly, the motion of a body in a circular path even with uniform speed is with variable velocity because in a circular path, the direction of motion of the body continuously changes with time. In fact, its velocity changes at a uniform rate. At any instant, its velocity is along the tangent to the circular path at that point. Fig. 2.5 shows the direction of velocity v at different points A, B, C and D of the circular path.

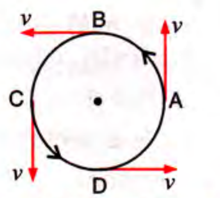

Fig. 2.5 Circular path of constant speed but variable velocity

In case of a body moving with non-uniform velocity, we specify the instantaneous velocity and the average velocity.

Instantaneous velocity : For a body moving with variable velocity, the velocity of the body at any instant is called its instantaneous velocity. It is measured by finding the ratio of the distance travelled in a sufficiently small time interval, to the time interval. It is important to have time interval small enough so that the direction of motion does not change during this interval.

Average velocity : If the velocity of a body moving in a particular direction changes with time, the ratio of displacement to the time taken in entire journey is called its average velocity. Thus,

$$\boxed{\textit{Average velocity} = \frac{\textit{Displacement}}{\textit{Total time taken}}} \quad ...(2.5)$$

Distinction between speed and velocity

(1) The speed is a scalar quantity, while velocity is a vector quantity. The speed of a body at a given time tells us how fast the body is moving at that time. The same information is also obtained by its velocity, but the velocity also tells us the direction in which the body is moving.

(2) For the motion in a straight line, the magnitude of velocity is its speed. The speed is always positive, but velocity is given positive or negative sign depending upon its direction of motion.

(3) *The average velocity of a body can be zero, even if its average speed is not zero.*
Examples : (i) If a body starts its motion from a point and comes back to the same point after a certain time, the displacement is zero, so the average velocity is also zero, but the total distance travelled is not zero and therefore, the average speed is not zero.

(ii) If a body moves in a circular path and covers equal distances in equal intervals of time, the speed is uniform, but due to continuous change in its direction of motion, its velocity is variable. The instantaneous velocity and instantaneous speed are not zero. The displacement for one round is zero and therefore, the average velocity is also zero, but the average speed is $2\pi r/T$ if r is the radius of path and T is the time taken in one round.

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* *Initially as the rain drop starts falling, first its velocity increases due to force of gravity, but very soon, due to viscosity (or friction) and upthrust of air, the viscous force and upthrust balances the force of gravity on the rain drop with the result that the net force on the drop becomes zero. Then the drop falls down with a uniform velocity called the terminal velocity.*

Distinction between speed and velocity

Speed	Velocity
1. The distance travelled per second by a moving object is called its speed.	1. The distance travelled per second by a moving object in a particular direction is called its velocity.
2. It is a scalar quantity. The speed does not tell us the direction of motion.	2. It is a vector quantity. The velocity tells us the speed as well as the direction of motion.
3. The speed is always positive since direction is not taken into consideration.	3. The velocity can be positive or negative depending upon the direction of motion.
4. After one round in a circular path, the average speed is not zero.	4. After completing each round in a circular path, the average velocity is zero.

2.5 ACCELERATION AND RETARDATION

Generally, bodies do not move with uniform velocities. The velocity of a body changes either in magnitude or in direction or both in magnitude as well as in direction. For example, the motion of a vehicle in a busy market, or while leaving or approaching a destination is with variable velocity. The motion of a planet or satellite in circular path is also with variable velocity.

Now we consider the motion only in a straight line path. Here there is no change in direction of motion and the change in velocity is only due to change in speed. In such a case, if the velocity of body increases with time, the motion is said to be *accelerated,* while if the velocity of body decreases with time, the motion is said to be *decelerated* (or *retarded*). Thus *retardation is the negative acceleration**.

Acceleration

Acceleration is the rate of change of velocity with time.*

Thus, acceleration is numerically equal to the change in velocity in 1 s. *i.e.*,

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time interval}} \quad ..(2.6)$$

Unit : Unit of acceleration = $\dfrac{\text{Unit of velocity}}{\text{Unit of time}}$

The S.I. unit of velocity is metre per second and of time is second.

$\therefore$ S.I. unit of acceleration is $\dfrac{\text{metre per second}}{\text{second}}$

= metre per second square or m s^{-2}.

* *Acceleration is the increase in velocity per second, while retardation is the decrease in velocity per second.*

The C.G.S. unit of acceleration is cm s^{-2}.

Relation for acceleration : Let a body be moving in a straight line in one direction with an initial velocity u. Its velocity changes in a short time interval t and the final velocity becomes v after time t. Then change in velocity = $(v - u)$ and time taken = t.

$$\left.\begin{aligned} \therefore \quad \text{Acceleration } a &= \frac{(v-u)}{t} \\ \text{or} \quad v &= u + a\,t \end{aligned}\right\} \quad ....(2.7)$$

If $v > u$, then a is positive, thus a is the acceleration. But if $v < u$, then a is negative, and a is the retardation.

Examples: (1) Suppose a car initially at rest, on starting acquires a velocity 20 m s^{-1} in 10 s. The change in its velocity is 20 m s^{-1} – 0 m s^{-1} = 20 m s^{-1}. This change has been brought about in 10 s. Therefore, the acceleration of car is

$$a = \frac{20\,\text{m s}^{-1} - 0\,\text{m s}^{-1}}{10\ \text{s}} = \frac{20\,\text{m s}^{-1}}{10\,\text{s}} = 2\ \text{m s}^{-2}.$$

(2) If a car initially moving with a velocity 25 m s^{-1} is brought to rest in 5 s by applying the brakes, then acceleration of the car is

$$a = \frac{0\,\text{m s}^{-1} - 25\,\text{m s}^{-1}}{5\ \text{s}} = \frac{-25\,\text{m s}^{-1}}{5\,\text{s}} = -5\ \text{m s}^{-2}$$

or retardation = 5 m s^{-2} (since negative acceleration is called the retardation).

Acceleration is a **vector quantity**. It is represented by the symbol $\vec{a}$. The direction of acceleration is the direction of change in velocity. For the motion in a straight line, the acceleration is in direction of motion of the body.

It may be mentioned here that *the acceleration of a body does not determine its direction of motion, while the velocity determines its direction of motion.* The positive or negative sign of acceleration tells us whether the velocity is increasing or decreasing with time, whereas the positive or negative sign of velocity tells its direction of motion.

Uniform acceleration : *The acceleration is said to be uniform (or constant) when equal changes in velocity take place in equal intervals of time.* The motion of a body under gravity (e.g. free fall of a body) is an example of uniformly accelerated motion.

Variable acceleration : *If change in velocity is not same in the same intervals of time, the acceleration is said to be variable.* The motion of a vehicle on a crowded (or hilly) road is with variable acceleration.

Acceleration due to gravity : *When a body falls freely under gravity, the acceleration produced in the body due to earth's gravitational attraction is called the acceleration due to gravity.* It is generally denoted by the letter g. When a body falls down, its velocity increases with time, so the acceleration is $+g$, while if the body moves vertically upwards, its velocity decreases with time, so the acceleration is $-g$ (or the retardation is g).

The average value of g is $9{\cdot}8$ m s^{-2} (or nearly 10 m s^{-2}). Actually it varies from place to place*. Thus if a body falls freely under gravity, its velocity increases at a rate of $9{\cdot}8$ m s^{-2}, *i.e.*, starting from rest, after 1 s the velocity will be $9{\cdot}8$ m s^{-1}, after 2 s the velocity will be $2 \times 9{\cdot}8 = 19{\cdot}6$ m s^{-1}; after 3 s, the velocity with be $3 \times 9{\cdot}8 = 29{\cdot}4$ m s^{-1} and so on. Similarly, if a body is projected vertically upwards, its velocity decreases at a rate of $9{\cdot}8$ m s^{-2}, *i.e.*, if a body is projected vertically upwards with an initial velocity of 49 m s^{-1}, after 1 s, its velocity will become $39{\cdot}2$ m s^{-1}; after 2 s, its velocity will become $29{\cdot}4$ m s^{-1}; after 3 s, its velocity will become $19{\cdot}6$ m s^{-1} and so on.

Note : The value of g does not depend on the mass of the body. Hence if two bodies of different masses are simultaneously dropped from a height, both will reach the ground simultaneously in vacuum because then there is no effect of friction and buoyancy due to air.

* *On the earth surface, g is maximum at the poles and minimum at the equator. The value of g decreases with altitude and also with depth from the earth's surface.*

EXAMPLES

1. Select the scalars and vectors from the following :
Velocity, distance, acceleration, work, mass, retardation.

Scalars : distance, work, mass.

Vectors : velocity, acceleration, retardation.

2. Express the speed 36 km h^{-1} in m s^{-1}.

$$36 \text{ km h}^{-1} = \frac{36 \text{ km}}{1 \text{ h}} = \frac{36 \times 1000 \text{ m}}{60 \times 60 \text{ s}} = \mathbf{10 \text{ m s}^{-1}}$$

3. Find the distance travelled by a body in 5 minutes if it travels with a uniform speed of 20 m s^{-1}.

Given, $u = 20$ m s^{-1}, $t = 5$ min $= 5 \times 60$ s $= 300$ s

$$\begin{aligned} \text{Distance travelled } S &= \text{speed } u \times \text{time } t \\ &= 20 \text{ m s}^{-1} \times 300 \text{ s} \\ &= 6000 \text{ m} = \mathbf{6 \text{ km}}. \end{aligned}$$

4. A train moving with uniform speed covers a distance of 120 m in 2 s. Calculate : (i) the speed of the train, (ii) the time it will take to cover 240 m.

Given, $S = 120$ m, $t = 2$ s

(i) Speed of the train $= \dfrac{\text{Distance travelled}}{\text{Time taken}}$

or $u = \dfrac{120 \text{ m}}{2 \text{ s}} = \mathbf{60 \text{ m s}^{-1}}$

(ii) Time taken to cover 240 m distance

$$t = \frac{\text{distance}}{\text{speed}} = \frac{240 \text{ m}}{60 \text{ m s}^{-1}} = \mathbf{4 \text{ s}}$$

5. A body rises vertically up to a height of 125 m in 5 s and then comes back at the point of projection. Find : (i) the total distance travelled, (ii) the displacement, (iii) the average speed and (iv) the average velocity of the body.

Given, $S = 125$ m, $t = 5$ s

(i) Total distance travelled $= S + S = 2S$

$= 2 \times 125$ m

$= \mathbf{250\ m}$

(ii) Displacement = **0** (since final position is same as initial position).

(iii) Average speed $= \dfrac{\text{Total distance travelled}}{\text{Total time of journey}}$

$$= \frac{2S}{2t} = \frac{2 \times 125\text{ m}}{2 \times 5\text{ s}}$$

$$= \frac{250\text{ m}}{10\text{ s}} = \mathbf{25\ m\ s^{-1}}$$

(iv) Average velocity = **0** (since displacement is zero).

6. A train first travels for 30 min with a velocity 30 km h^{-1} and then for 40 min with a velocity 40 km h^{-1} in the same direction, Calculate : (i) the total distance travelled, (ii) the average velocity of the train.

Given, $t_1 = 30\text{ min} = \frac{1}{2}\text{ h}$, $v_1 = 30\text{ km h}^{-1}$,

$t_2 = 40\text{ min} = \frac{2}{3}\text{ h}$, $v_2 = 40\text{ km h}^{-1}$.

(i) Distance travelled = velocity × time

$$\therefore \quad S_1 = v_1 \times t_1 = 30 \times \frac{1}{2} = 15\text{ km}$$

$$S_2 = v_2 \times t_2 = 40 \times \frac{2}{3} = \frac{80}{3}\text{ km}$$

Total distance travelled $S = S_1 + S_2$

$$= 15 + \frac{80}{3} = \frac{125}{3}\text{ km} = \mathbf{41{\cdot}67\ km}$$

(ii) Total time of journey $t = t_1 + t_2$

$$= \frac{1}{2} + \frac{2}{3} = \frac{7}{6}\text{ h}$$

$$\therefore \text{ Average velocity} = \frac{\text{Total distance travelled } S}{\text{Total time of journey } t}$$

$$= \frac{41{\cdot}67\text{ km}}{(7/6)\text{ h}} = \mathbf{35{\cdot}71\ km\ h^{-1}}.$$

7. A car travels a distance 50 km with a velocity 25 km h^{-1} and then 60 km with a velocity 20 km h^{-1} in the same direction. Calculate : (i) the total time of journey and (ii) the average velocity of the car.

Given, $S_1 = 50\text{ km}$, $v_1 = 25\text{ km h}^{-1}$,

$S_2 = 60\text{ km}$, $v_2 = 20\text{ km h}^{-1}$.

(i) Time of journey $t = \dfrac{\text{Distance } S}{\text{velocity } v}$

$$\therefore \quad t_1 = \frac{S_1}{v_1} = \frac{50\text{ km}}{25\text{ km h}^{-1}} = 2\text{ h}$$

$$t_2 = \frac{S_2}{v_2} = \frac{60\text{ km}}{20\text{ km h}^{-1}} = 3\text{ h}$$

Total time of journey $t = t_1 + t_2 = 2\text{ h} + 3\text{ h} = \mathbf{5\ h}$

(ii) Total distance travelled $S = S_1 + S_2$

$= 50\text{ km} + 60\text{ km} = 110\text{ km}$

$$\text{Average velocity} = \frac{\text{Total distance travelled } S}{\text{Total time of journey } t}$$

$$= \frac{110\text{ km}}{5\text{ h}} = \mathbf{22\ km\ h^{-1}}.$$

8. The velocity of an object increases at a constant rate from 20 m s^{-1} to 50 m s^{-1} in 10 s. Find the acceleration.

Given, $u = 20\text{ m s}^{-1}$, $v = 50\text{ m s}^{-1}$, $t = 10$ s

$$\text{Acceleration } a = \frac{v-u}{t} = \frac{50\text{ m s}^{-1} - 20\text{ m s}^{-1}}{10\text{ s}}$$

or $$a = \frac{30\text{ m s}^{-1}}{10\text{ s}} = \mathbf{3\ m\ s^{-2}}.$$

9. A pebble thrown vertically upwards with an initial velocity 50 m s^{-1} comes to a stop in 5 s. Find the retardation.

Given, $u = 50\text{ m s}^{-1}$, $v = 0$, $t = 5$ s

$$\text{Acceleration } a = \frac{v-u}{t} = \frac{0 - 50\text{ m s}^{-1}}{5\text{ s}}$$

$$= -10\text{ m s}^{-2}$$

Hence, retardation = $\mathbf{10\ m\ s^{-2}}$.

10. The table below shows the distance in cm, travelled by the objects *A*, *B* and *C* during each second.

Time	Distance (in cm) covered in each second by *A*, *B* and *C*		
	Object *A*	Object *B*	Object *C*
1st second	20	20	20
2nd second	20	36	60
3rd second	20	24	100
4th second	20	30	140
5th second	20	48	180

(i) Which object is moving with constant speed ? Give a reason for your answer.

(ii) Which object is moving with a constant acceleration ? Give a reason.

(iii) Which object is moving with irregular acceleration ?

(i) The object *A* is moving with constant speed. The reason is that it covers equal distance (= 20 cm) in each second.

(ii) The object *C* is moving with a constant acceleration. The reason is that for the object *C*,

the distance covered in each second (*i.e.*, velocity) increases by the same amount (= 40 m s^{-1}) in each interval of one second.

(iii) The object ***B*** is moving with irregular acceleration. The reason is that the change in velocity is not same in each interval of one second.

EXERCISE 2(A)

1. Differentiate between the scalar and vector quantities, giving *two* examples of each.
2. State whether the following quantity is a scalar or vector ?
   (a) pressure (b) force
   (c) momentum (d) energy
   (e) weight (f) speed.
   Ans. (a) scalar (b) vector (c) vector (d) scalar (e) vector (f) scalar.
3. When is a body said to be at rest ?
4. When is a body said to be in motion ?
5. What do you mean by motion in one direction ?
6. Define displacement. State its unit.
7. Differentiate between distance and displacement.
8. Can displacement be zero even if distance is not zero ? Give *one* example to explain your answer.
9. When is the magnitude of displacement equal to the distance ?
   Ans. When the motion is in a fixed direction
10. Define velocity. State its unit.
11. Define speed. What is its S.I. unit ?
12. Distinguish between speed and velocity.
13. Which of the quantity speed or velocity gives the direction of motion of body ? **Ans.** Velocity
14. When is the instantaneous speed same as the average speed ?
15. Distinguish between the uniform velocity and the variable velocity.
16. Distinguish between the average speed and the average velocity.
17. Give an example of the motion of a body moving with a constant speed, but with a variable velocity. Draw a diagram to represent such a motion.
18. Give an example of motion in which average speed is not zero, but the average velocity is zero.
19. Define acceleration. State its S.I. unit.
20. Distinguish between acceleration and retardation.
21. Differentiate between uniform acceleration and variable acceleration.
22. What is meant by the term retardation ? Name its S.I. unit.
23. Which of the quantity, velocity or acceleration determines the direction of motion ? **Ans.** Velocity
24. Give *one* example of each type of the following motion :
    (a) uniform velocity (b) variable velocity
    (c) variable acceleration (d) uniform retardation.
25. The diagram (Fig. 2.6) below shows the pattern of the oil dripping on the road, at a constant rate from a moving car. What informations do you get from it about the motion of car ?

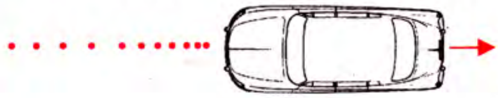


Fig. 2.6

Ans. Initially it is moving with a constant speed and then it slows down.

26. Define the term acceleration due to gravity. State its average value.
27. 'The value of *g* remains same at all places on the earth surface'. Is this statement true ? Give reason for your answer.
    Ans. No. The value of *g* is maximum at poles and minimum at equator on the earth surface.
28. If a stone and a pencil are dropped simultaneously in vacuum from the top of a tower, which of the two will reach the ground first ? Give reason.
    Ans. Both will reach the ground simultaneously, since acceleration due to gravity is same (= *g*) on both.

Multiple choice type :

1. The vector quantity is :
   (a) work (b) pressure
   (c) distance (d) velocity
   Ans. (d) velocity
2. The S.I. unit of velocity is :
   (a) km h^{-1} (b) m min^{-1}
   (c) km min^{-1} (d) m s^{-1} **Ans.** (d) m s^{-1}
3. The unit of retardation is :
   (a) m s^{-1} (b) m s^{-2}
   (c) m (d) m s^2 **Ans.** (b) m s^{-2}
4. A body when projected up with an initial velocity *u* goes to a height *h* in time *t* and then comes back at the point of projection. The correct statement is :
   (a) the average velocity is $2h/t$
   (b) the acceleration is zero

(c) the final velocity on reaching the point of projection is $2u$.
(d) the displacement is zero.

Ans. (d) the displacement is zero.

5. 18 km h^{-1} is equal to :
(a) 10 m s^{-1} (b) 5 m s^{-1}
(c) 18 m s^{-1} (d) 1·8 m s^{-1} **Ans.** (b) 5 m s^{-1}

Numericals :

1. The speed of a car is 72 km h^{-1}. Express it in m s^{-1}. **Ans.** 20 m s^{-1}
2. Express 15 m s^{-1} in km h^{-1}. **Ans.** 54 km h^{-1}
3. Express each of the following in m s^{-1} :
(a) 1 km h^{-1} (b) 18 km min^{-1}
Ans. (a) 0·278 m s^{-1} (b) 300 m s^{-1}
4. Arrange the following speeds in increasing order : 10 m s^{-1}, 1 km min^{-1}, 18 km h^{-1}.
Ans. 18 km h^{-1}, 10 m s^{-1}, 1 km min^{-1}
5. A train takes 3 h to travel from Agra to Delhi with a uniform speed of 65 km h^{-1}. Find the distance between the two cities. **Ans.** 195 km
6. A car travels first 30 km with a uniform speed of 60 km h^{-1} and then next 30 km with a uniform speed of 40 km h^{-1}. Calculate : (i) the total time of journey, (ii) the average speed of the car.
Ans. (i) 75 min, (ii) 48 km h^{-1}.
7. A train takes 2 h to reach station B from station A, and then 3 h to return from station B to station A. The distance between the two stations is 200 km. Find : (i) the average speed, (ii) the average velocity of the train. **Ans.** (i) 80 km h^{-1}, (ii) zero.
8. A car moving on a straight path covers a distance of 1 km due east in 100 s. What is (i) the speed and (ii) the velocity, of car ?
Ans. (i) 10 m s^{-1}, (ii) 10 m s^{-1} due east.
9. A body starts from rest and acquires a velocity 10 m s^{-1} in 2 s. Find the acceleration.
Ans. 5 m s^{-2}
10. A car starting from rest acquires a velocity 180 m s^{-1} in 0·05 h. Find the acceleration.
Ans. 1 m s^{-2}
11. A body is moving vertically upwards. Its velocity changes at a constant rate from 50 m s^{-1} to 20 m s^{-1} in 3 s. What is its acceleration ?
Ans. -10 m s^{-2}. The negative sign shows that the velocity decreases with time, so retardation is 10 m s^{-2}.
12. A toy car initially moving with a uniform velocity of 18 km h^{-1} comes to a stop in 2 s. Find the retardation of the car in S.I. units. **Ans.** 2·5 m s^{-2}
13. A car accelerates at a rate of 5 m s^{-2}. Find the increase in its velocity in 2 s. **Ans.** 10 m s^{-1}
14. A car is moving with a velocity 20 m s^{-1}. The brakes are applied to retard it at a rate of 2 m s^{-2}. What will be the velocity after 5 s of applying the brakes ?. **Ans.** 10 m s^{-1}
15. A bicycle initially moving with a velocity 5·0 m s^{-1} accelerates for 5 s at a rate of 2 m s^{-2}. What will be its final velocity ? **Ans.** 15·0 m s^{-1}
16. A car is moving in a straight line with speed 18 km h^{-1}. It is stopped in 5 s by applying the brakes. Find : (i) the speed of car in m s^{-1}, (ii) the retardation and (iii) the speed of car after 2 s of applying the brakes.
Ans. (i) 5 m s^{-1}, (ii) 1 m s^{-2}, (iii) 3 m s^{-1}

(B) GRAPHICAL REPRESENTATION OF LINEAR MOTION

If a body moves in a straight line path, its motion is in one dimension and is called the linear or rectilinear motion. A linear motion can be well studied with the help of the following graphs :

(i) Displacement-time graph,
(ii) Velocity-time graph, and
(iii) Acceleration-time graph.

Note : For motion in one direction in a straight line since the direction of motion does not change, so the displacement-time graph and the distance-time graph are same. Similarly the velocity-time graph and the speed-time graph are also same. They differ in two and three dimensional motions.

2.6 DISPLACEMENT-TIME GRAPH

In the displacement-time graph, the time is taken on X-axis and the displacement of body is taken on Y-axis. From this graph, we can determine the velocity of the body.

Since, velocity is the ratio of displacement and time, therefore *the slope of displacement-time graph gives the velocity*. If the slope is positive, it implies that the body is moving away from the starting (or reference) point, but if the slope is negative, the body is returning towards the starting (or reference) point.

Let us consider the following situations :

Case (1) : If the position of a body does not change with time, the body is said to be *stationary* and the displacement as measured from the origin at all instant is same as that at $t = 0$, so the displacement-time graph is a straight line parallel to the time axis as shown in Fig. 2.7. In Fig. 2.7, *OP* is the distance of the body from the origin *O* and it remains same at each instant.

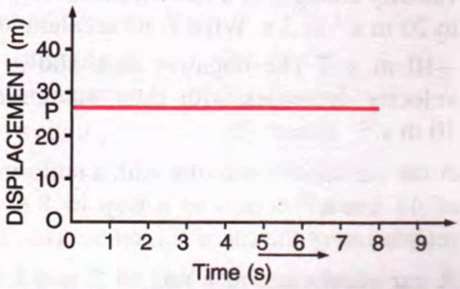


Fig. 2.7 Displacement-time graph for a stationary object

Case (2) : If a body is moving with uniform velocity, its displacement increases by the same amount in each second and so the displacement-time graph is a straight line inclined to the time axis. The velocity of body can be obtained by finding the slope of the straight line.

Example (1) : A car is moving on a *straight path in a given direction* with a uniform speed. The following table represents its displacement (*i.e.*, distance from the starting point) at different instants.

Time in second (s)	0	1	2	3	4	5
Displacement in metre (m)	0	10	20	30	40	50

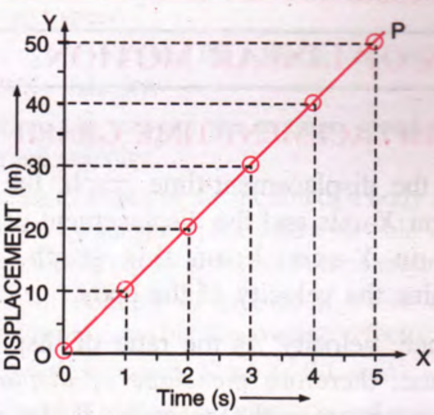


Fig. 2.8 Displacement-time graph with a uniform velocity

The displacement-time graph is a straight line *OP* inclined to the time axis (Fig. 2.8). It shows the linear relationship between the displacement and time (*i.e.*, the displacement of car is directly proportional to the time of travel or the car travels equal distance in equal intervals of time in a certain direction). Thus

> *For a body moving with uniform velocity, the displacement is directly proportional to the time (i.e., $S \propto t$)*

The velocity of car can be obtained by finding the slope of the straight line *OP*. For this, take any two points *A* and *B* on the line *OP* as shown in Fig. 2.9 and draw perpendiculars *AD* and *BE* on the *Y*-axis and *AF* and *BG* on the *X*-axis from these points.

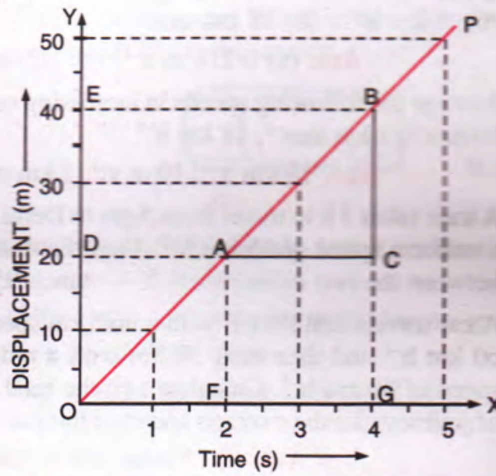


Fig. 2.9 To find velocity from displacement-time graph

From graph in Fig. 2.9, velocity of car

= slope of the line *OP*

$$= \frac{BC}{CA} = \frac{ED}{GF} = \frac{(40-20)\ \text{m}}{(4-2)\ \text{s}} = \frac{20\ \text{m}}{2\ \text{s}} = 10\ \text{m s}^{-1}$$

Obviously, ***larger the slope (i.e., more inclined is the straight line), higher is the velocity.***

Example (2) : Fig. 2.10 represents the displacement-time graph of a ball which while moving on a perfectly smooth floor hits a wall at $t = 6$ s and then comes back along the same line. The displacement (*i.e.*, distance of ball from the starting point) at different instants of time is given in the table below.

Time (in second)	0	2	4	6	8	10	12	14
Displacement (in metre)	0	20	40	60	45	30	15	0

In Fig. 2.10,

$$\text{Slope of the line } OA = \frac{60\ \text{m} - 0}{6\ \text{s} - 0} = 10\ \text{m s}^{-1}$$

$$\text{and slope of the line } AB = \frac{0 - 60\ \text{m}}{14\ \text{s} - 6\ \text{s}} = -\frac{60\ \text{m}}{8\ \text{s}} = -7{\cdot}5\ \text{m s}^{-1}$$

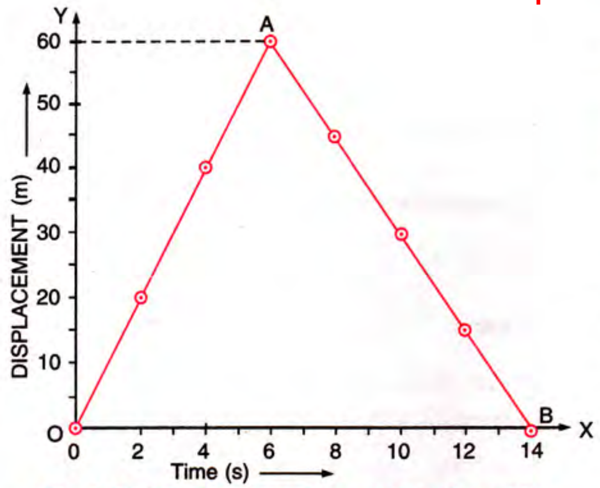


Fig. 2.10 Displacement-time graph with positive and negative slopes

Thus the slope of the line OA is positive ($= 10 \text{ m s}^{-1}$) which represents the uniform motion of ball with velocity 10 m s^{-1} towards the wall (*i.e.*, away from the starting point), while the slope of the line AB is negative ($= -7{\cdot}5 \text{ m s}^{-1}$) which represents the uniform motion of ball with velocity $7{\cdot}5 \text{ m s}^{-1}$ towards the starting point after hitting the wall.

Note : The displacement–time graph can never be a straight line, parallel to the displacement axis because such a line would mean that the distance covered by the body in a certain direction increases without any increase in time (*i.e.*, the velocity of the body is infinite) which is impossible.

Case (3) : If a body moves with varying speed in a fixed direction *i.e.*, with variable velocity, the displacement-time graph is not a straight line, but it is a curve. *The velocity at any instant can then be obtained by finding the slope (or the gradient) of the tangent drawn on the curve at that instant of time.*

Example : Fig. 2.11 represents the displacement-time graph of a body for which

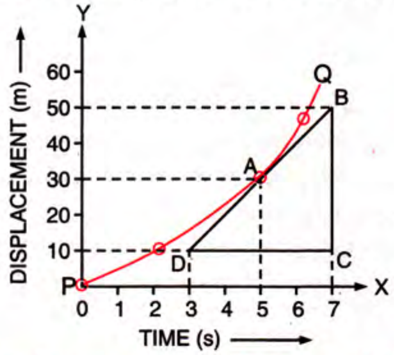


Fig. 2.11 Displacement-time graph with a variable velocity

displacement (*i.e.*, distance from the starting point) at different instants is given in the table below.

Time (in second)	0	2	5	6
Displacement (in metre)	0	10	30	47

The displacement-time graph is a curve PQ.

The velocity of body at time $t = 5$ s (or when the displacement $S = 30$ m) is obtained by finding the slope of the tangent BD to the curve drawn at the point A corresponding to $t = 5$ s or $S = 30$ m. Slope of the tangent BD is

$$\text{Slope} = \frac{BC}{CD} = \frac{(50-10)\text{ m}}{(7-3)\text{ s}} = \frac{40\text{ m}}{4\text{ s}} = 10\text{ m s}^{-1}$$

i.e., the velocity of body at $t = 5$ s or $S = 30$ m is 10 m s^{-1}.

Note that in this case, the slope of the curve is different at different points, so the velocity is different at different instants.

Conclusions :

(i) (a) If the displacement-time graph of an object, is a straight line parallel to the time axis, the object is stationary. (b) If the graph is a straight line inclined to the time axis, the motion is with uniform velocity. (c) If the graph is a curve, the motion is with non-uniform velocity.

(ii) In the displacement-time graph, the slope of the straight line (or the tangent to the curve at an instant) gives the velocity of the object at that instant. (a) If the slope is positive, it represents the motion away from the origin (or reference point). (b) If the slope is negative, it represents the motion towards the origin.

(iii) Knowing the velocity of the object at different instants from the displacement-time graph, the velocity-time graph can be drawn.

2.7 VELOCITY-TIME GRAPH

In the velocity-time graph, time is taken on X-axis and the velocity is taken on Y-axis.

Since velocity is a vector quantity, the positive velocity means that the body is moving in a certain direction away from its initial position and the negative velocity means that the body is moving in the opposite direction (*i.e.*, towards the initial position).

From the velocity-time graph, we can determine (a) the displacement of the body in a certain time interval and (b) the acceleration of the body at any instant.

(a) *Determination of displacement from the velocity-time graph :* Since, velocity × time = displacement, *the area enclosed between the velocity-time sketch and X-axis (i.e., the time axis) gives the displacement of the body.*

The area enclosed above the time axis represents the positive displacement *i.e.,* the distance travelled away from the starting point, while the area enclosed below the time axis represents the negative displacement *i.e.,* the distance travelled towards the starting point. The total displacement is obtained by adding them numerically with proper sign. But *the total distance travelled by the body is their arithmetic sum* (without sign).

Example : Consider the velocity-time graph of a body in motion as shown in Fig. 2.12.

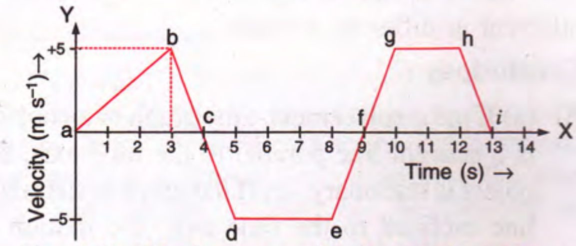


Fig. 2.12 Velocity-time graph of a body in motion

In Fig. 2.12, area of $\Delta\, abc$

$$= \frac{1}{2} \times \text{base} \times \text{height}$$

$$= \frac{1}{2} \times 4\text{ s} \times 5\text{ m s}^{-1} = 10\text{ m},$$

area of trapezium *cdef*

$$= \frac{1}{2} \times (\text{sum of parallel sides}) \times \text{height}$$

$$= \frac{1}{2} \times (5+3)\text{ s} \times 5\text{ m s}^{-1} = 20\text{ m},$$

and area of trapezium *fghi*

$$= \frac{1}{2} \times (4+2)\text{ s} \times 5\text{ m s}^{-1} = 15\text{ m}$$

Then the displacement of the body = area of $\Delta\, abc$ – area of trapezium *cdef* + area of trapezium *fghi* = 10 m – 20 m + 15 m = 5 m, but the total distance travelled by body = area of $\Delta\, abc$ + area of trapezium *cdef* + area of trapezium *fghi* = 10 m + 20 m + 15 m = 45 m.

(b) *Determination of acceleration from the velocity-time graph :* Since acceleration is equal to the ratio of change in velocity and time taken, therefore *the slope (or gradient) of the velocity-time sketch gives the acceleration.*

Example : In Fig. 2.12, for the part *ab* of the motion

$$\text{Slope} = \frac{\text{Change in velocity}}{\text{Change in time}} = \frac{(5-0)\text{ m s}^{-1}}{(3-0)\text{ s}}$$

$$\therefore \text{ Acceleration} = \frac{5}{3} = 1{\cdot}67\text{ m s}^{-2}$$

In part *bd*,

$$\text{Slope} = \frac{[(-5)-5]\text{ m s}^{-1}}{(5-3)\text{ s}} = -5\text{ m s}^{-2}$$

$$\therefore \text{ Acceleration} = -5\text{ m s}^{-2}$$

In part *de*, slope = 0, ∴ Acceleration = 0

Since the slope is positive in part *ab*, it is the accelerated motion; the slope is negative in part *bd*, the motion is decelerated or retarded and in part *de* the slope is zero, so the motion is with constant velocity.

Now we can consider the following cases :

Case (1) : If a body is in motion with *uniform velocity* (*i.e.*, velocity remains constant with time), the velocity-time graph is a straight line parallel to the time axis.

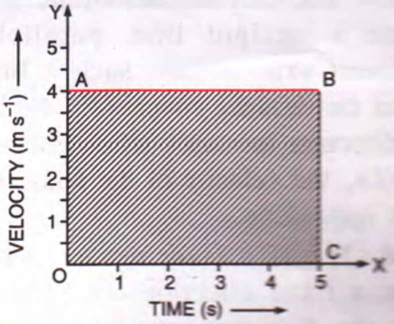


Fig. 2.13. Velocity-time graph for uniform velocity

Example : In Fig. 2.13, a straight line *AB* represents the velocity-time graph of a body moving with a uniform velocity 4 m s^{-1} for 5 s. The slope of the straight line *AB* is zero, therefore, its acceleration is zero.

Displacement in 5 second = area of the rectangle $OABC = OC \times OA = 5\text{ s} \times 4\text{ m s}^{-1} = 20\text{ m}$.

Case (2) : (a) If the body is in motion with uniform acceleration (*i.e.*, equal changes in velocity take place in equal intervals of time), the velocity-time graph is a straight line inclined to the time axis. *The slope of the line gives the acceleration.*

Example : The table below represents the velocity of a body at different instants, starting from rest.

Time (in s)	0	1	2	3	4	5	6	7	8
Velocity (in m s^{-1})	0	10	20	30	40	50	60	70	80

Obviously, the velocity is increasing by an equal amount in each second *i.e.*, the body is moving with uniform acceleration. The velocity-time graph is a straight line *OP* inclined to the time axis as shown in Fig. 2.14.

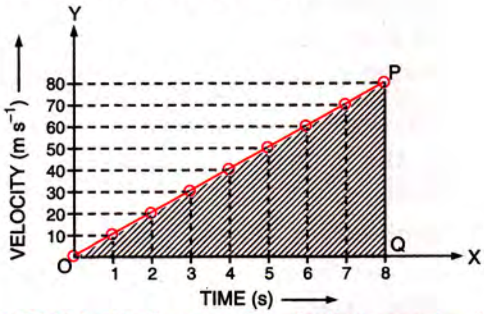


Fig. 2.14 Velocity-time graph; velocity increasing by equal amount in each second

Distance travelled by the body in 8 second

$$S = \text{area of triangle } OPQ$$

$$= \frac{1}{2} \times \text{base} \times \text{height}$$

$$= \frac{1}{2} \times \text{OQ} \times \text{QP}$$

$$= \frac{1}{2} \times 8 \text{ s} \times 80 \text{ m s}^{-1} = 320 \text{ m.}$$

Acceleration of the body = Slope of the line *OP*

$$= \frac{PQ}{QO} = \frac{(80-0) \text{ m s}^{-1}}{(8-0) \text{ s}}$$

$$= \frac{80 \text{ m s}^{-1}}{8 \text{ s}} = 10 \text{ m s}^{-2}$$

(b) If the motion is with uniform retardation (*i.e.*, its velocity decreases by an equal amount in each second), the velocity-time graph will be a straight line inclined to the time axis with a negative slope.

Example : In Fig. 2.15, the straight line *AB* represents the velocity-time graph for a body

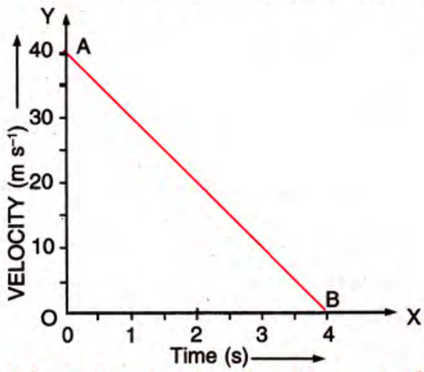


Fig. 2.15 Velocity-time graph with uniform retardation

initially moving with a velocity 40 m s^{-1} which comes to a stop in 4 s with uniform retardation.

Distance travelled by the body in 4 s

$$= \text{Area of triangle } AOB$$

$$= \frac{1}{2} OB \times OA$$

$$= \frac{1}{2} \times 4 \text{ s} \times 40 \text{ m s}^{-1} = 80 \text{ m}$$

Retardation of the body

$$= - \text{Slope of the line } AB$$

$$= -\frac{OA}{BO} = -\frac{(0-40) \text{ m s}^{-1}}{(4-0) \text{ s}}$$

$$= \frac{40}{4} \text{ m s}^{-2} = 10 \text{ m s}^{-2}.$$

Obviously, *on velocity-time graph, larger the slope (i.e., more inclined is the straight line), higher is the acceleration or retardation.*

(c) The velocity-time graph can never be a straight line parallel to the velocity axis because such a line would mean that the velocity increases without any increase in time (*i.e.*, acceleration is infinite) which is impossible.

(d) If the body initially is moving with some velocity and then it accelerates, the velocity-time sketch for the accelerated motion will start from the point on the velocity axis corresponding to the initial velocity of the body.

Example : In Fig. 2.16, straight line *AB* represents the velocity-time graph of a car initially moving with velocity 10 m s^{-1} and then with uniform acceleration. Its velocity at different instants is as given in the following table :

Time (in second)	0	1	2	3	4	5
Velocity (in m s^{-1})	10	15	20	25	30	35

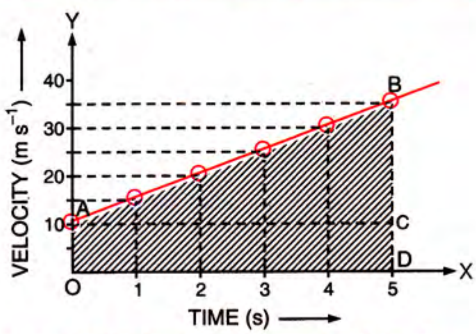


Fig. 2.16 Velocity-time graph when the body is initially not at rest

(i) Displacement of the car in 5 second

$= \text{Area of trapezium } ABDO$

$= \frac{1}{2}(OA + DB) \times OD$

$= \frac{1}{2} \times (10 + 35) \times 5$

$= \frac{1}{2} \times 45 \times 5 = 112{\cdot}5 \text{ m}$

(ii) Acceleration of the car = slope of the line AB

$= \frac{BC}{CA} = \frac{(35-10)\text{ m s}^{-1}}{(5-0)\text{ s}}$

$= \frac{25\text{ m s}^{-1}}{5\text{ s}} = 5 \text{ m s}^{-2}.$

Case (3) : Consider the motion of a body released from a height to fall down vertically, initially from rest with velocity increasing uniformly for 5 s and acquiring the velocity 50 m s^{-1}. Then after hitting the ground, it rises vertically upwards to the same height with velocity decreasing uniformly. In this case, the velocity-time graph is shown in Fig. 2.17 in which part AB shows the downward journey of body with positive velocity while part CD shows the upward journey with negative velocity (since the direction of motion has reversed).

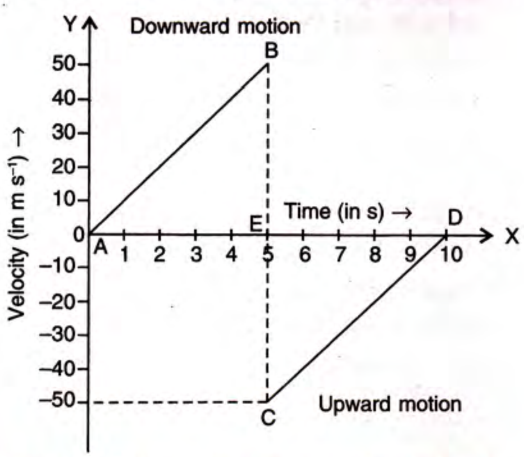


Fig. 2.17 Velocity-time graph for free fall and the rise of a body

(a) In part AB, acceleration = Slope of line AB

$= \frac{50\text{ m s}^{-1} - 0\text{ m s}^{-1}}{5\text{ s}} = 10 \text{ ms}^{-2}$

In part CD, retardation = – Slope of line CD

$= -\frac{0\text{ m s}^{-1} - 50\text{ m s}^{-1}}{(10-5)\text{ s}} = 10 \text{ ms}^{-2}$

(b) Total distance travelled in 10 s = area of triangle ABE + area of triangle CDE

$= \frac{1}{2} \times 5\text{ s} \times 50\text{ m s}^{-1} + \frac{1}{2} \times 5\text{ s} \times 50\text{ m s}^{-1}$

$= 250 \text{ m}$

Displacement in 10 s = 0 (zero).

Since initial and final positions are same.

Conclusions :

(i) (a) For motion with a uniform velocity, the velocity-time graph is a straight line parallel to time axis. (b) If the velocity-time graph is a straight line inclined to the time axis, the motion is with uniform acceleration. (c) If the velocity-time graph is a curve, the motion is with non-uniform acceleration.

(ii) The slope of the straight line (or the tangent to the curve at an instant) gives the acceleration at that instant. (a) The positive slope means velocity increasing with time *i.e.*, accelerated motion. (b) The negative slope means velocity decreasing with time *i.e.*, retardated motion and (c) the zero slope implies motion with constant velocity.

(iii) Knowing the acceleration (*i.e.*, slope) at different instants from the velocity-time graph, we can draw the acceleration-time graph.

(iv) The area enclosed between the velocity-time sketch and the time axis for a certain time interval gives the displacement in that interval of time. The area above the time axis gives the positive displacement, while the area below the time axis gives the negative displacement.

(v) Knowing the distance (or displacement) in different time intervals from the velocity-time graph, we can draw the distance-time (or displacement-time) graph.

2.8 ACCELERATION – TIME GRAPH

In the acceleration-time graph, time is taken on X-axis and acceleration is taken on Y-axis. From this graph, we can find the change in speed in a certain interval of time. For linear motion, acceleration × time = change in speed, therefore *from the area enclosed between the acceleration-time sketch and the time axis, we get the change in speed of the body for the given time interval.*

Let us consider the following cases :

Case (1) : If the body is stationary or if it is moving with a uniform velocity, the acceleration is zero. The acceleration-time graph in such a

case is a straight line coinciding with the time axis (Fig 2.18).

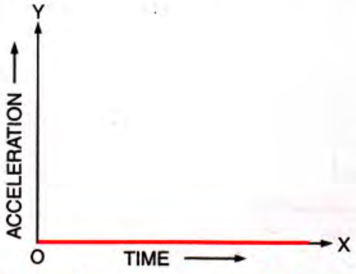


Fig. 2.18. Acceleration-time graph for motion with uniform velocity

Case (2) : If the velocity of body in motion increases uniformly with time, the acceleration is constant (*i.e.*, the motion is uniformly accelerated). In such a case, the acceleration-time graph is a straight line parallel to the time axis on the positive acceleration axis. In Fig. 2.19, the straight line *PQ* represents the acceleration-time graph of a body moving with a constant acceleration (= *OP*).

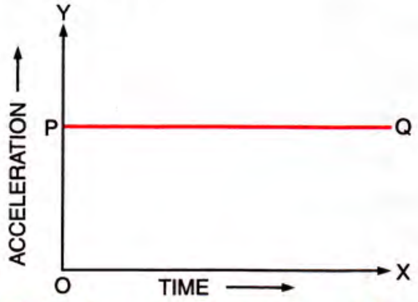


Fig. 2.19. Acceleration-time graph for uniform acceleration

Case (3) : If the velocity of body decreases at a constant rate, the retardation is constant (*i.e.*, the motion is uniformly retarded). The acceleration-time graph is a straight line parallel to the time axis on the negative acceleration axis. In Fig 2.20, the straight line *PQ* represents the acceleration-time graph for a body moving with a constant retardation (= *OP*).

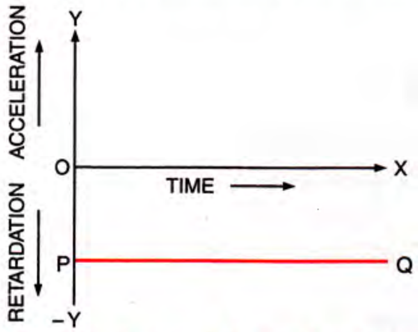


Fig. 2.20. Acceleration-time graph for uniform retardation

Case (4) : If the velocity of body changes in an irregular manner, the acceleration is variable. The acceleration-time graph will then be a curve of any shape.

2.9 MOTION UNDER GRAVITY

A body falling freely under gravity moves with a uniform acceleration of 9·8 m s^{-2} *(or nearly* 10 m s^{-2}*). For a body moving vertically upwards, there is a uniform retardation of* 9·8 m s^{-2}. Thus motion under gravity is an example of uniformly accelerated or uniformly retarded motion.

Here we shall consider the motion of a freely falling body under gravity and we shall use the acceleration-time graph to obtain the velocity-time graph and the displacement-time graph. The acceleration-time graph for such a motion is a straight line parallel to the time axis.

In Fig. 2.21, straight line *AF* represents the acceleration-time graph for a body falling freely (or moving) with uniform acceleration equal to 10 m s^{-2}.

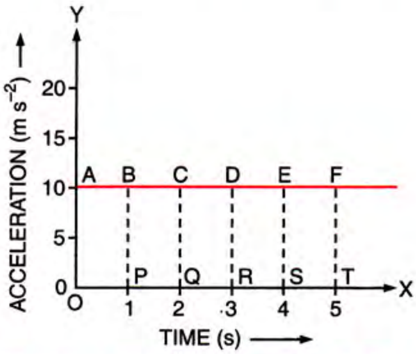


Fig. 2.21 Acceleration-time graph for a freely falling body

This graph can be used to obtain the velocity-time graph, by finding the area enclosed between the straight line and the time axis for each interval of time of 1 s. Let the initial velocity at $t = 0$ be zero, then

Velocity after 1 s = Area *OABP* $= 10 \times 1 = 10$ m s^{-1}

Velocity after 2 s = Area *OACQ* $= 10 \times 2 = 20$ m s^{-1}

Velocity after 3 s = Area *OADR* $= 10 \times 3 = 30$ m s^{-1}

Velocity after 4 s = Area *OAES* $= 10 \times 4 = 40$ m s^{-1}

Velocity after 5 s = Area *OAFT* $= 10 \times 5 = 50$ m s^{-1}

The velocity-time graph from the above data is shown in Fig. 2.22, which is a straight line OA inclined with the time axis and having a slope of 10 m s^{-2} (which is equal to the acceleration of the body).

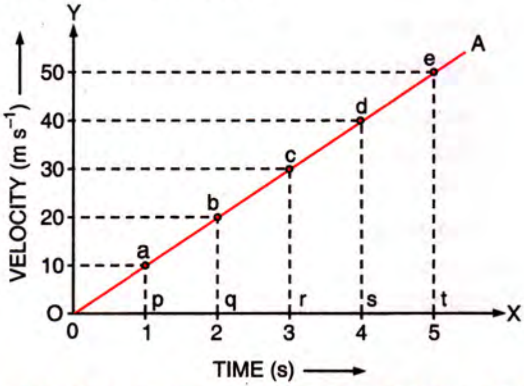


Fig. 2.22 Velocity-time graph for a freely falling body

The velocity-time graph (Fig. 2.22) can be used to obtain the displacement-time graph by finding the area enclosed by the straight line OA with the time axis at each interval of time of 1 s.

Displacement in 1 s = Area of $\Delta\, oap = \frac{1}{2} \times 1 \times 10 = 5$ m

Displacement in 2 s = Area of $\Delta\, obq = \frac{1}{2} \times 2 \times 20 = 20$ m

Displacement in 3 s = Area of $\Delta\, ocr = \frac{1}{2} \times 3 \times 30 = 45$ m

Displacement in 4 s = Area of $\Delta\, ods = \frac{1}{2} \times 4 \times 40 = 80$ m

Displacement in 5 s = Area of $\Delta\, oet = \frac{1}{2} \times 5 \times 50 = 125$ m.

The displacement-time graph from the above data is shown in Fig. 2.23 which is a curve OA (parabola).

It may be noted that *for a freely falling body, the displacement is directly proportional to the square of time* ($S \propto t^2$). The table below represents

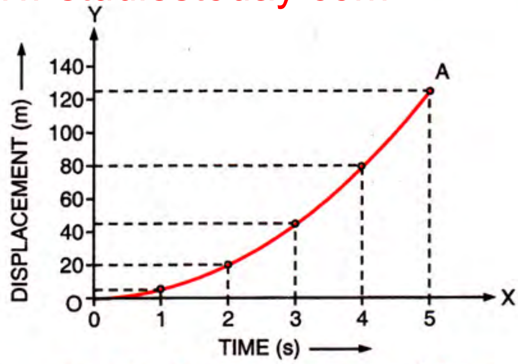


Fig. 2.23 Displacement-time graph for a freely falling body

the square of time (t^2) and displacement (S) from the above data.

Square of time t^2 (s^2)	1	4	9	16	25
Displacement S (m)	5	20	45	80	125

Now a graph plotted by taking the displacement (S) on Y-axis and the square of time (t^2) on X-axis is a straight line OA as shown in Fig. 2.24 with

the slope $= \dfrac{(80-20)\text{ m s}^{-1}}{(16-4)\text{ s}} = \dfrac{60}{12} \text{ m s}^{-2} = 5 \text{ m s}^{-2}$.

The slope is half the acceleration due to gravity. Thus, the value of acceleration due to gravity (g) can be obtaned by doubling the slope of the S–t^2 graph for a freely falling body.

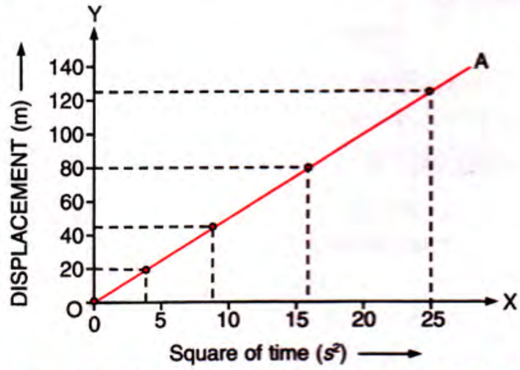


Fig. 2.24 $S - t^2$ graph for a freely falling body

EXAMPLES

1. The following table represents the distance of a car at different instants in a fixed direction.

Time (s)	0	1	2	3	4	5
Distance (m)	0	10	20	30	40	50

(a) Draw displacement–time graph and with its help, find whether the motion of car is uniform or non-uniform?

(b) Use graph to calculate :

(i) the velocity of car

(ii) the displacement of car at t = 2·5 s and t = 4·5 s.

(a) The displacement–time graph for the car is shown in Fig. 2.25. Since it is a straight line

OA inclined with the time axis, so the motion of car is with **uniform velocity**.

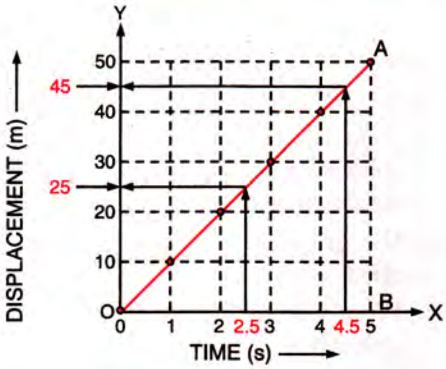


Fig. 2.25

(b) (i) Velocity = Slope of the straight line OA

$$= \frac{BA}{OB} = \frac{(50-0)\ \text{m}}{(5-0)\ \text{s}} = \frac{50\ \text{m}}{5\ \text{s}} = \mathbf{10\ m\ s^{-1}}$$

(ii) From the graph, it is clear that at t = 2·5 s, displacement is **25 m** and at t = 4·5 s, displacement is **45 m**.

2. Fig 2.26 shows the displacement-time graph for the motion of two boys *A* and *B* along a straight road in the same direction.

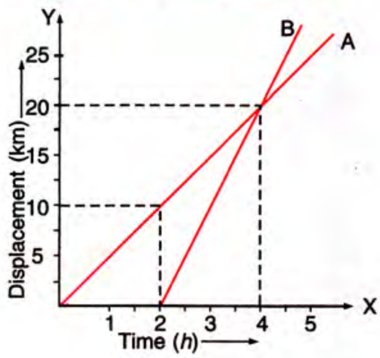


Fig. 2.26

Answer the following :

(i) When did *B* start after *A* ?

(ii) How far away was *A* from *B* when *B* started ?

(iii) Which of the two has greater velocity ?

(iv) When and where did *B* overtake *A* ?

(i) B started his motion **2 h later** from the start of A.

(ii) When B started, A was at distance **10 km away from *B*.**

(iii) ***B* has greater velocity than *A*** since the straight line on graph for B has greater slope than that for A.

(iv) B overtook A at the instant when both were at the same place. This position is at the point where the two straight lines meet each other. For this point, **distance from the starting point is 20 km and time is 4 h**. Thus B overtook A when A has travelled for 4 h (or B has travelled for 4 – 2 = 2 h) at distance 20 km from the starting point

3. A car travels with a uniform velocity of 20 m s^{-1} for 5 s. The brakes are then applied and the car is uniformly retarded. It comes to rest in further 8 s. Draw a graph of velocity against time. Use this graph to find :

(i) the distance travelled in first 5 s,

(ii) the distance travelled after the brakes are applied,

(iii) total distance travelled, and

(iv) acceleration during the first 5 s and last 8 s.

The graph of velocity against time is shown in Fig. 2.27.

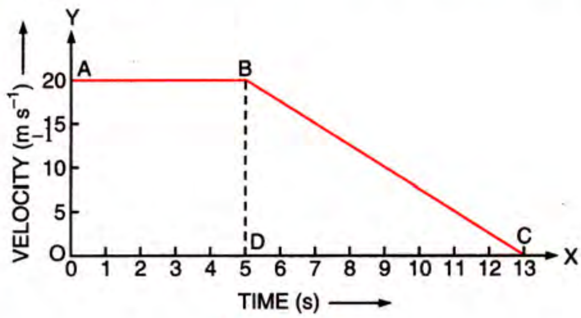


Fig. 2.27

(i) The distance travelled in first 5 s = area of rectangle $OABD = OD \times OA$ = 5 s × 20 m s^{-1} = **100 m**

(ii) The distance travelled by car after the brakes are applied = area of $\Delta\, BDC = \frac{1}{2} \times DC \times DB$

$$= \frac{1}{2} \times (13-5)\ \text{s} \times 20\ \text{m s}^{-1} = \mathbf{80\ m}.$$

(iii) Total distance travelled

= area of rectangle $OABD$ + area of triangle BDC

= 100 + 80 = **180 m**

(iv) Acceleration in the first 5 s (in part AB) = **0** (since straight line AB is parallel to the time axis, so slope = 0).

Acceleration in the last 8 s (in part BC)

= Slope of the line BC

$$= \frac{BD}{DC} = \frac{(0-20)\ \text{m s}^{-1}}{(13-5)\ \text{s}} = \frac{-20\ \text{m s}}{8\ \text{s}}$$

$= \mathbf{-\ 2{\cdot}5\ m\ s^{-2}}$

Since acceleration is negative, so retardation $= 2{\cdot}5\ \text{m s}^{-2}$.

4. A train starts from rest and accelerates uniformly at 100 m minute^{-2} for 10 minutes. Find the velocity acquired by the train. It then maintains a constant velocity for 20 minutes. The brakes are then applied and the train is uniformly retarded. It comes to rest in 5 minutes. Draw a velocity–time graph and use it to find :

(i) the retardation in the last 5 minutes,

(ii) total distance travelled, and

(iii) the average velocity of the train.

Initial velocity = 0, time interval = 10 minute, acceleration = 100 m minute^{-2}.

$$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time interval}} = \frac{\text{Final velocity} - 0}{\text{Time interval}}$$

or Final velocity = acceleration × time interval

$= 100\ \text{m minute}^{-2} \times 10\ \text{minute}$

$= 1000\ \text{m minute}^{-1}$

∴ The final velocity acquired = 1000 m minute^{-1}.

The velocity–time graph is shown in Fig 2.28.

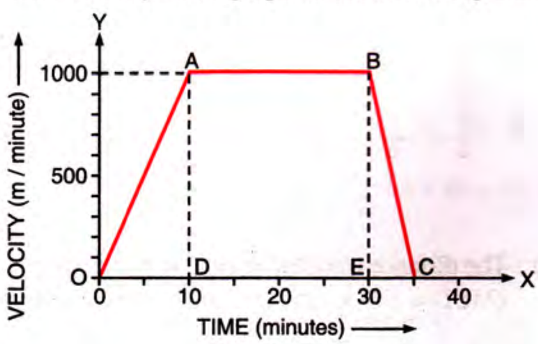


Fig. 2.28

(i) Retardation in the last 5 minutes

= – Slope of the line *BC*.

$$= -\frac{BE}{EC} = -\frac{(0-1000)\ \text{m minute}^{-1}}{(35-30)\ \text{minute}}$$

$$= -\frac{-1000\ \text{m minute}^{-1}}{5\ \text{minute}} = \mathbf{200\ m\ minute^{-2}}$$

(ii) Total distance travelled

= Area of trapezium *OABC*

$= \frac{1}{2}(OC + AB) \times AD$

$= \frac{1}{2}(35 + 20)\ \text{minute} \times 1000\ \text{m minute}^{-1}$

$= 55 \times 500$ m

= **27500 m** (or **27·5 km**).

(iii) Average velocity $= \dfrac{\text{Total distance travelled}}{\text{Total time of travel}}$

$$= \frac{27500\ \text{m}}{35\ \text{minute}} = \mathbf{785{\cdot}7\ m\ minute^{-1}}.$$

5. A stone is thrown vertically upwards with an initial velocity of 40 m s^{-1}. Taking $g = 10$ m s^{-2}, draw the velocity–time graph of the motion of stone till it comes back on the ground.

(i) Use graph to find the maximum height reached by the stone.

(ii) What is the net displacement and total distance covered by the stone ?

(i) Given, $u = 40\ \text{m s}^{-1}$, $g = 10\ \text{m s}^{-2}$.

As the stone rises up, the velocity decreases at the rate of 10 m s^{-2}. When the velocity becomes zero, the stone is at its highest position. Then it begins to fall and its velocity increases at a rate of 10 m s^{-2}. The velocity of stone at different instants is shown in the following table (the upward direction is taken positive).

Time (in s)	0	1	2	3	4	5	6	7	8
Velocity (in m s^{-1})	40	30	20	10	0	–10	–20	–30	–40

Fig. 2.29 shows the velocity–time graph.

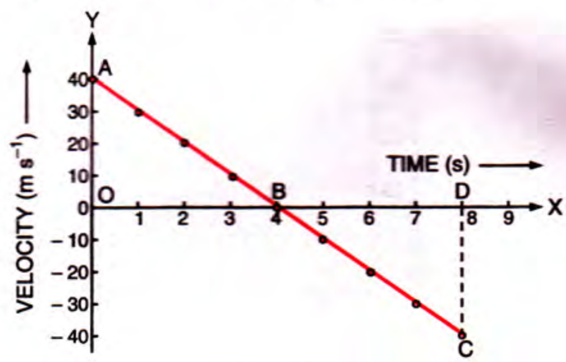


Fig. 2.29

Maximum height reached by the stone

= Area of Δ *OAB*

$= \frac{1}{2}\ OB \times OA$

$= \frac{1}{2} \times 4\ \text{s} \times 40\ \text{m s}^{-1} = \mathbf{80\ m}$.

(ii) Net displacement

= Area of Δ *OAB* – Area of Δ *BDC*

$= \frac{1}{2}\ OB \times OA - \frac{1}{2}\ BD \times DC$

$= (\frac{1}{2} \times 4\ \text{s} \times 40\ \text{m s}^{-1}) - (\frac{1}{2} \times 4\ \text{s} \times 40\ \text{m s}^{-1}) = \mathbf{0}$

Total distance covered

$$= \text{Area of } \Delta\, OAB + \text{Area of } \Delta\, BDC$$
$$= 80 \text{ m} + 80 \text{ m} = \mathbf{160 \text{ m}}$$

6. A car starting from rest, accelerates at a rate of 2 m s^{-2} for 5 s. For this journey, (a) draw the velocity-time graph (b) draw the displacement-time graph using the velocity-time graph in part (a).

(a) Given, $u = 0$, $a = 2$ m s^{-2}.

The velocity of car at different instants is given in the table below :

Time (in s)	0	1	2	3	4	5
Velocity (in m s^{-1})	0	2	4	6	8	10

Fig. 2.30 shows the velocity-time graph.

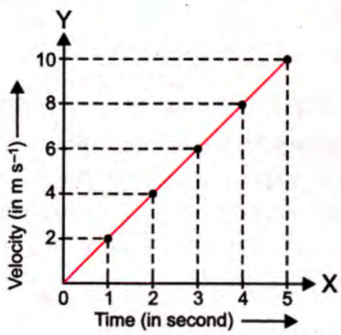


Fig. 2.30 Velocity-time graph

(b) From Fig. 2.30, the displacement of car at any instant can be obtained by finding the area enclosed by the straight line with the time axis up to that instant.

At $t = 1$ s, displacement $S = \frac{1}{2} \times 1 \times 2 = 1$ m

At $t = 2$ s, displacement $S = \frac{1}{2} \times 2 \times 4 = 4$ m

At $t = 3$ s, displacement $S = \frac{1}{2} \times 3 \times 6 = 9$ m

At $t = 4$ s, displacement $S = \frac{1}{2} \times 4 \times 8 = 16$ m

At $t = 5$ s, displacement $S = \frac{1}{2} \times 5 \times 10 = 25$ m

The table below gives the displacement of car at different instants.

Time (in s)	0	1	2	3	4	5
Displacement (in m)	0	1	4	9	16	25

The displacement-time graph is shown in Fig. 2.31.

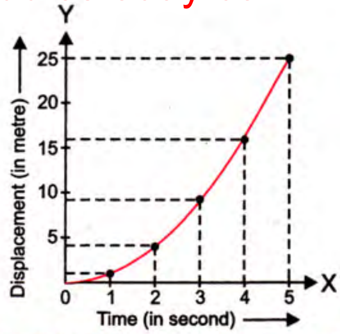


Fig. 2.31 Displacement-time graph

7. The following table represents the velocity of a moving body at different instants of time.

Time (s)	0	5	10	15	20	25	30
Velocity (m s^{-1})	10	15	20	20	30	15	0

Draw the velocity–time graph and answer the following :

(i) For which interval of time the body has a uniform motion ? Find the velocity in this time interval?

(ii) For which interval of time the body has the accelerated motion ? Calculate the acceleration.

(iii) For which interval of time, the body has retardation ? Calculate the retardation.

The velocity–time graph is shown in Fig. 2.32.

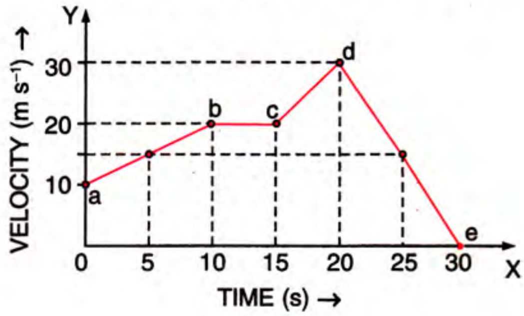


Fig. 2.32

(i) The body has uniform motion from t = **10 s to** t = **15 s** in part bc since velocity is constant and is equal to 20 m s^{-1} during this interval.

(ii) The body has the accelerated motion from t = **0 s to** t = **10 s** in part ab, and also from t = **15 s to** t = **20 s** in part cd since velocity is increasing with time during these intervals.

From $t = 0$ to $t = 10$ s, in part ab

Acceleration a = Slope of the straight line ab

$$= \frac{(20-10)\,\text{m s}^{-1}}{(10-0)\,\text{s}} = \frac{10\,\text{m s}^{-1}}{10\,\text{s}} = \mathbf{1 \text{ m s}^{-2}}$$

From $t = 15$ s to $t = 20$ s, in part *cd*

Acceleration a' = Slope of the line *cd*

$$= \frac{(30-20)\,\text{m s}^{-1}}{(20-15)\,\text{s}} = \frac{10\,\text{m s}^{-1}}{5\,\text{s}} = \mathbf{2\ m\ s^{-2}}$$

(iii) The body has retardation **from $t = 20$ s to $t = 30$ s**, in part *de*.

Retardation = – Slope of the line *de*

$$= -\frac{(0-30)\,\text{m s}^{-1}}{(30-20)\,\text{s}} = -\frac{-30\,\text{m s}^{-1}}{10\,\text{s}} = \mathbf{3\ m\ s^{-2}}$$

EXERCISE 2 (B)

1. For the motion with uniform velocity, how is the distance travelled related to the time ?
   Ans. Distance is directly proportional to time.
2. What informations about the motion of a body are obtained from the displacement–time graph ?
3. (a) What does the slope of a displacement–time graph represent ?
   (b) Can displacement–time sketch be parallel to the displacement axis ? Give reason to your answer.
4. What can you say about the nature of motion of a body if its displacement–time graph is
   (a) a straight line parallel to time axis ?
   (b) a straight line inclined to the time axis with an acute angle ?
   (c) a straight line inclined to the time axis with an obtuse angle ?
   (d) a curve.
   Ans. (a) body is stationary (or no motion), (b) motion away from the starting point with uniform velocity (c) motion towards the starting point with uniform velocity (d) motion with variable velocity.
5. Draw a displacement–time graph for a boy going to school with a uniform velocity.
6. State how the velocity–time graph can be used to find (i) the acceleration of a body, (ii) the distance travelled by the body in a given time, and (iii) the displacement of the body in a given time.
7. Fig. 2.33 shows displacement–time graph of two vehicles *A* and *B* moving along a straight road. Which vehicle is moving faster ? Give reason.

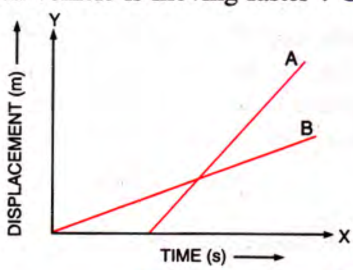


Fig. 2.33 **Ans.** Vehicle *A*

Reason : Slope of line *A* is more than that of line *B*.

8. State the type of motion represented by the following sketches in Fig. 2.34 (a) and (b).

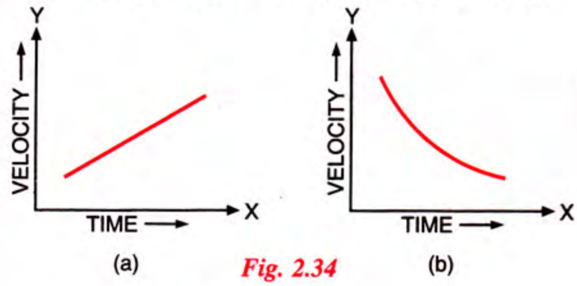


Fig. 2.34

Give example of each type of motion.

Ans. (a) Uniformly accelerated motion e.g. motion of a body released downward.
(b) Motion with a variable retardation e.g. a car approaching its destination.

9. Draw a velocity–time graph for a body moving with an initial velocity *u* and uniform acceleration *a*. Use this graph to find the distance travelled by the body in time *t*.
10. What does the slope of velocity–time graph represent ? **Ans.** Acceleration
11. Fig 2.35 shows the velocity–time graph for two cars *A* and *B* moving in same direction. Which car has the greater acceleration ? Give reason to your answer.

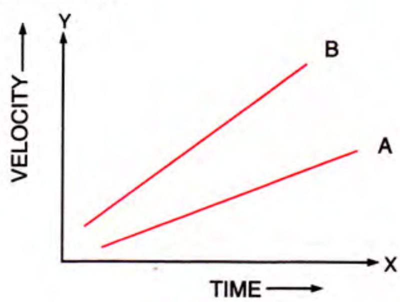


Fig. 2.35 **Ans.** *B*

Reason : Slope of straight line for car *B* is more than that of line *A*.

12. Fig. 2.36 shows the displacement–time graph for four bodies *A*, *B*, *C* and *D*. In each case state what information do you get about the acceleration (zero, positive or negative).

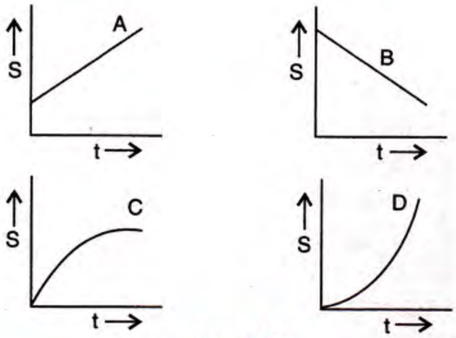


Fig. 2.36

Ans. ***A*** **:** Zero acceleration since slope (*i.e.*, velocity) is constant, ***B*** **:** zero acceleration since slope is constant, ***C*** **:** negative acceleration (or retardation) since slope is decreasing with time, ***D*** **:** positive acceleration since slope is increasing with time.

13. Draw the shape of the velocity–time graph for a body moving with (a) uniform velocity, (b) uniform acceleration.
14. The velocity-time graph for a uniformly retarded body is a straight line inclined to the time axis with an obtuse angle. How is retardation calculated from the velocity-time graph ?

 Ans. By finding the negative slope.
15. Draw a graph for acceleration against time for a uniformly accelerated motion. How can it be used to find the change in speed in a certain interval of time ?
16. Draw a velocity–time graph for the free fall of a body under gravity, starting from rest. Take $g = 10$ m s^{-2}.
17. How is the distance related with time for the motion under uniform acceleration such as the motion of a freely falling body ? **Ans.** $S \propto t^2$
18. A body falls freely from a certain height. Show graphically the relation between the distance fallen and square of time. How will you determine g from this graph ?

Multiple choice type :

1. The velocity-time graph of a body in motion is a straight line inclined to the time axis. The correct statement is :
 (a) velocity is uniform
 (b) acceleration is uniform
 (c) both velocity and acceleration are uniform
 (d) neither velocity nor acceleration is uniform.

 Ans. (b) acceleration is uniform.
2. For uniform motion :
 (a) the distance-time graph is a straight line parallel to the time axis.
 (b) the speed-time graph is a straight line inclined to the time axis.
 (c) the speed-time graph is a straight line parallel to the time axis.
 (d) the acceleration-time graph is a straight line parallel to the time axis.

 Ans. (c) the speed-time graph is a straight line parallel to the time axis.
3. For a uniformly retarded motion, the velocity-time graph is :
 (a) a curve
 (b) a straight line parallel to the time axis
 (c) a straight line perpendicular to the time axis.
 (d) a straight line inclined to the time axis.

 Ans. (d) a straight line inclined to the time axis

Numericals :

1. Fig. 2.37 (a) shows the displacement–time graph for the motion of a body. Use it to calculate the velocity of body at $t = 1$ s, 2 s and 3 s, then draw the velocity–time graph for it in Fig. (b).

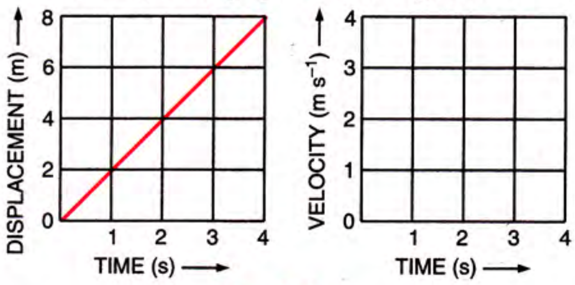


Fig. 2.37

2. Following table gives the displacement of a car at different instants of time.

Time (s)	0	1	2	3	4
Displacement (m)	0	5	10	15	20

 (a) Draw the displacement–time sketch and find the average velocity of car.
 (b) What will be the displacement of car at (i) 2·5 s and (ii) 4·5 s ?

 Ans. (a) 5 m s^{-1}, (b) (i) 12·5 m, (ii) 22·5 m.
3. A body is moving in a straight line and its displacement at various instants of time is given in the following table :

Time (s)	0	1	2	3	4	5	6	7
Displacement (m)	2	6	12	12	12	18	22	24

 Plot displacement–time graph and calculate :
 (i) total distance travelled in interval 1 s to 5 s,
 (ii) average velocity in time interval 1 s to 5 s.

 Ans. (i) 12 m (ii) 3 m s^{-1}

4. Fig. 2.38 shows the displacement of a body at different times.

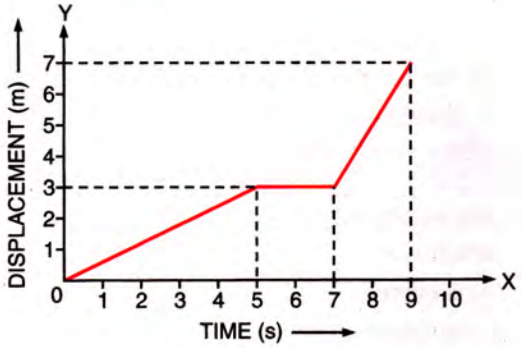


Fig. 2.38

(a) Calculate the velocity of the body as it moves for time interval (i) 0 to 5 s, (ii) 5 s to 7 s and (iii) 7 s to 9 s.

(b) Calculate the average velocity during the time interval 5 s to 9 s.

[**Hint :** From 5 s to 9 s, displacement = 7 m − 3 m = 4 m]

Ans. (a) (i) 0·6 m s^{-1}, (ii) 0 m s^{-1}, (iii) 2 m s^{-1}, (b) 1 m s^{-1}

5. From the displacement–time graph of a cyclist, given in Fig. 2.39, find :

(i) the average velocity in the first 4 s,

(ii) the displacement from the initial position at the end of 10 s,

(iii) the time after which he reaches the starting point.

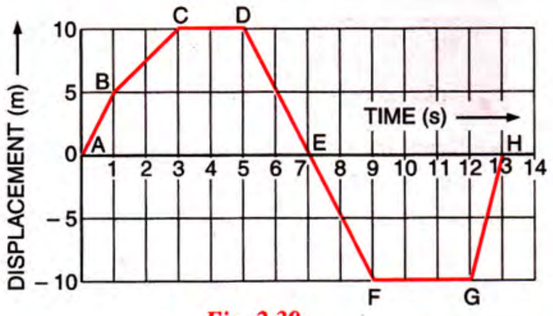


Fig. 2.39

Ans. (i) 2·5 m s^{-1}, (ii) −10 m, (iii) 7 s and 13 s.

6. Fig. 2.40 ahead represents the displacement–time sketch of motion of two cars *A* and *B*. Find :

(i) the distance by which the car *B* was initially ahead of car *A*.

(ii) the velocities of car *A* and car *B*.

(iii) the time in which the car *A* catches the car *B*.

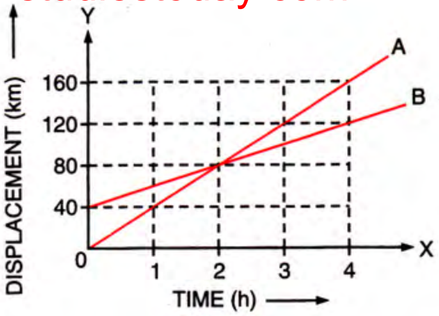


Fig. 2.40

(iv) the distance from start when the car *A* will catch the car *B*.

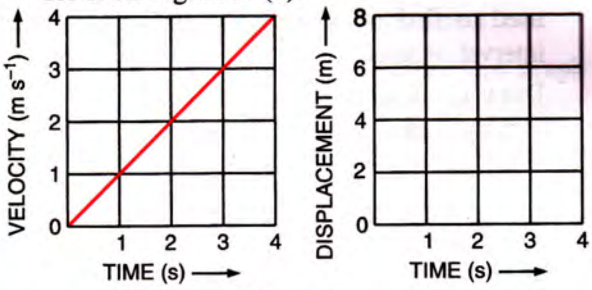
Ans. (i) 40 km, (ii) ***A***— 40 km h^{-1}, ***B***— 20 km h^{-1} (iii) 2 h, (iv) 80 km.

7. A body at rest is made to fall from the top of a tower. Its displacement at different instants is given in the following table :

Time (in s)	0·1	0·2	0·3	0·4	0·5	0·6
Displacement (in m)	0·05	0·20	0·45	0·80	1·25	1·80

Draw a displacement–time graph and state whether the motion is uniform or non-uniform ?

8. Fig. 2.41 (a) shows the velocity–time graph for the motion of a body. Use it to find the displacement of the body at *t* = 1 s, 2 s, 3 s and 4 s, then draw the displacement–time graph for it on Fig. 2.41 (b).



(a) *Fig. 2.41* (b)

9. Fig. 2.42 given below shows a velocity–time graph for a car starting from rest. The graph has three parts *AB*, *BC* and *CD*.

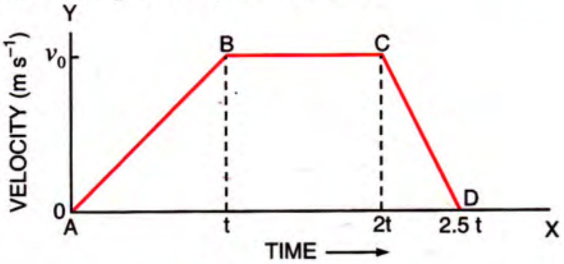


Fig. 2.42

(i) State how is the distance travelled in any part determined from this graph.

(ii) Compare the distance travelled in part *BC* with the distance travelled in part *AB*.

(iii) Which part of graph shows motion with uniform (a) velocity (b) acceleration (c) retardation ?

(iv) (a) Is the magnitude of acceleration higher or lower than that of retardation ? Give a reason. (b) Compare the magnitude of acceleration and retardation.

Ans. (i) By finding the area enclosed by the graph in that part with the time axis (ii) 2 : 1 (iii) (a) *BC* (b) *AB* (c) *CD* (iv) (a) lower, as slope of line *AB* is less than that of the line *CD*, (b) 1 : 2.

10. The velocity–time graph of a moving body is given below in Fig. 2.43.

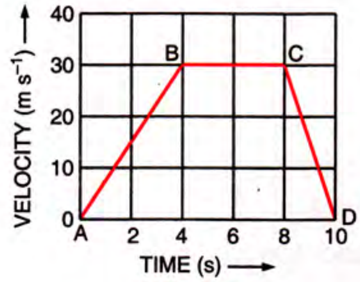


Fig. 2.43

Find :

(i) the acceleration in parts *AB*, *BC* and *CD*.

(ii) displacement in each part *AB*, *BC*, *CD*, and

(iii) total displacement.

Ans. (i) ***AB*** : 7·5 m s^{-2}, ***BC*** : 0 m s^{-2}, ***CD*** : – 15 m s^{-2} (ii) ***AB*** : 60 m, ***BC*** : 120 m, ***CD*** : 30 m (iii) 210 m

11. A ball moves on a smooth floor in a straight line with a uniform velocity 10 m s^{-1} for 6 s. At $t = 6$ s, the ball hits a wall and comes back along the same line to the starting point with same speed. Draw the velocity-time graph and use it to find the total distance travelled by the ball and its displacement.

Ans. Distance = 120 m, displacement = 0.

12. Fig. 2.44 shows the velocity-time graph of a particle moving in a straight line.

(i) State the nature of motion of particle.

(ii) Find the displacement of particle at $t = 6$ s.

(iii) Does the particle change its direction of motion ?

(iv) Compare the distance travelled by the particle from 0 to 4 s and from 4 s to 6 s.

(v) Find the acceleration from 0 to 4 s and retardation from 4 s to 6 s.

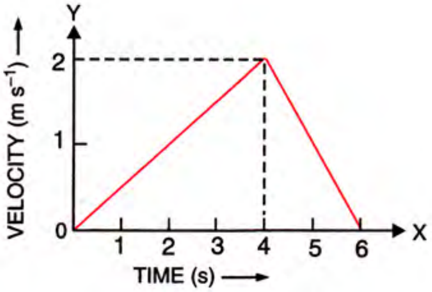


Fig. 2.44

Ans. (i) Uniformly accelerated from 0 to 4 s and then uniformly retarded from 4 s to 6 s. (ii) 6 m (iii) No, (iv) 2 : 1 (v) acceleration = 0·5 m s^{-2}, retardation = 1 m s^{-2}.

(C) EQUATIONS OF MOTION

2.9 EQUATIONS OF UNIFORMLY ACCELERATED MOTION

For motion of a body moving with a uniform acceleration, the following *three* equations give the relationship between initial velocity (u), final velocity (v), acceleration (a), time of journey (t) and distance travelled (S) :

$$\left.\begin{aligned}&(1)\ \ v = u + at\\ &(2)\ \ S = \frac{1}{2}(u+v)\,t = ut + \frac{1}{2}at^2 \ \text{ and}\\ &(3)\ \ v^2 = u^2 + 2aS\end{aligned}\right\}\quad ...(2.8)$$

Derivation

(1) Graphical method (from velocity-time graph)

Consider the linear motion of a body with an initial velocity u. The body accelerates uniformly and in time t, it acquires the final velocity v. The velocity-time graph is a straight line *AB* as shown in Fig. 2.45.

It is evident from the graph that

Initial velocity (at $t = 0$) = $OA = u$

Final velocity (at time t) = $OC = v$

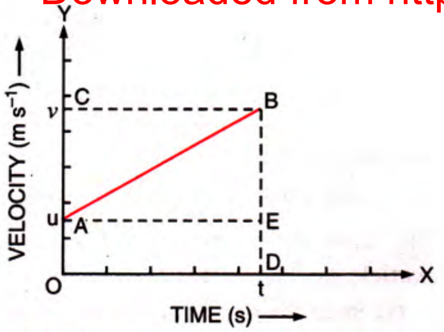


Fig. 2.45 Graph showing the linear motion with uniform acceleration

(i) Acceleration $a =$ Slope of the line AB

or $a = \frac{EB}{AE} = \frac{AC}{OD} = \frac{OC - OA}{OD} = \frac{v-u}{t}$

or $at = v - u$

or $\boxed{v = u + at}$ ... (2.9)

(ii) The distance S travelled in time t

= area of the trapezium $OABD$

= area of rectangle $OAED$ + area of triangle ABE

or $S = OA \times OD + \frac{1}{2} \times BE \times AE$

$= u \times t + \frac{1}{2} \times (v-u) \times t$ ..(2.10)

But from eqn (2.9), $v - u = at$

∴ From eqn. (2.10),

$$\boxed{S = ut + \frac{1}{2}at^2} \quad ...(2.11)$$

(iii) The distance S travelled in time t

= area of the trapezium $OABD$

or $S = \frac{1}{2}(OA + DB) \times OD$

or $S = \frac{1}{2}(u+v) \times t$ ... (2.12)

From eqn. (2.9), $t = \frac{v-u}{a}$

∴ From eqn (2.12),

∴ $S = \frac{1}{2}(u+v) \times \left(\frac{v-u}{a}\right) = \frac{1}{2}\left(\frac{v^2-u^2}{a}\right)$

or $2aS = v^2 - u^2$

or $\boxed{v^2 = u^2 + 2aS}$ ... (2.13)

(2) Alternative method

(i) By definition,

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken}}$$

$$= \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time taken}}$$

or $a = \frac{v-u}{t}$

or $at = v - u$

or $v = u + at$ ...(1)

(ii) Distance travelled = Average velocity × time

$= \left(\frac{\text{Initial velocity} + \text{Final velocity}}{2}\right) \times \text{time}$

or $S = \frac{u+v}{2} \times t$

But from eqn. (1), $v = u + at$

∴ $S = \frac{u + (u+at)}{2} \times t$

or $S = \left(\frac{2u+at}{2}\right) \times t$

or $S = ut + \frac{1}{2}at^2$ ...(2)

(iii) Distance travelled = Average velocity × time

or $S = \frac{u+v}{2} \times t$

But from eqn. (1), $v = u + at$

or $t = \frac{v-u}{a}$

∴ $S = \frac{u+v}{2} \times \frac{v-u}{a} = \frac{v^2-u^2}{2a}$

or $v^2 - u^2 = 2aS$

or $v^2 = u^2 + 2aS$ ...(3)

Equations (1), (2) and (3) are same as the equations (2.9), (2.11) and (2.13).

Special cases

(a) When a body starts from rest, initial velocity is zero ($u = 0$), then

$$\left.\begin{array}{ll} \text{(i)} & v = at \\ \text{(ii)} & S = \frac{1}{2}at^2 \\ \text{(iii)} & v^2 = 2aS \end{array}\right\} \quad ...(2.14)$$

(b) If a body is moving with a uniform retardation, a will be negative. The equations of motion then take the form :

$$\left.\begin{array}{ll} \text{(i)} & v = u - at \\ \text{(ii)} & S = ut - \frac{1}{2}at^2 \\ \text{(iii)} & v^2 = u^2 - 2aS \end{array}\right\} \quad ...(2.15)$$

EXAMPLES

1. A car acquires a velocity of 72 km h^{-1} in 10 s starting from rest. Calculate :
(i) the acceleration,
(ii) the average velocity, and
(iii) the distance travelled in this time.

Given, initial velocity $u = 0$

Final velocity $v = 72$ km h^{-1}

$$= \frac{72 \times 1000 \text{ m}}{60 \times 60 \text{ s}} = 20 \text{ m s}^{-1}$$

Time taken $t = 10$ s

(i) Acceleration $a = \dfrac{v-u}{t}$

$$= \frac{(20-0) \text{ m s}^{-1}}{10 \text{ s}} = \mathbf{2 \text{ m s}^{-2}}$$

(ii) Average velocity $= \dfrac{u+v}{2}$

$$= \frac{0+20}{2} \text{ m s}^{-1} = \mathbf{10 \text{ m s}^{-1}}$$

(iii) Distance travelled S = average velocity × time

$= (10 \text{ m s}^{-1}) \times (10 \text{ s})$

$= \mathbf{100 \text{ m}}$

Alternative method :

Distance travelled $S = ut + \frac{1}{2} at^2$

$= 0 + \frac{1}{2} \times 2 \times (10)^2$

$= \mathbf{100 \text{ m}}$

2. A ball is initially moving with a velocity 0·5 m s^{-1}. Its velocity decreases at a rate of 0·05 m s^{-2}. (a) How much time will it take to stop ? (b) How much distance will the ball travel before it stops ?

Given, initial velocity $u = 0{\cdot}5$ m s^{-1}, final velocity $v = 0$, acceleration $a = -0{\cdot}05$ m s^{-2} (Here negative sign is used since velocity decreases with time).

(a) From equation of motion $v = u + at$

$$0 = 0{\cdot}5 - 0{\cdot}05 \times t$$

or $0{\cdot}05\, t = 0{\cdot}5$

or $t = \dfrac{0{\cdot}5}{0{\cdot}05} = \mathbf{10 \text{ s}}$

(b) From equation of motion $v^2 = u^2 + 2a\,S$

$$0 = (0{\cdot}5)^2 - 2 \times 0{\cdot}05 \times S$$

or $0{\cdot}1\, S = 0{\cdot}25$ or $S = \dfrac{0{\cdot}25}{0{\cdot}1} = \mathbf{2{\cdot}5 \text{ m}}$

3. A body initially at rest travels a distance 100 m in 5 s with a constant acceleration. Calculate : (i) the acceleration, and (ii) the final velocity at the end of 5 s.

Given, initial velocity $u = 0$, distance $S = 100$ m, time taken $t = 5$ s.

(i) From equation of motion $S = ut + \frac{1}{2} at^2$

$$100 = 0 \times 5 + \frac{1}{2} \times a \times (5)^2$$

or $100 = \frac{1}{2} \times 25\, a$

or Acceleration $a = \dfrac{100 \times 2}{25} = \mathbf{8 \text{ m s}^{-2}}$

(ii) From equation of motion $v = u + at$

Final velocity $v = 0 + 8 \times 5 = \mathbf{40 \text{ m s}^{-1}}$.

4. A car initially at rest starts moving with a constant acceleration of 0·5 m s^{-2} and travels a distance of 25 m. Find : (i) its final velocity and (ii) the time taken.

Given, initial velocity $u = 0$,

acceleration $a = 0{\cdot}5$ m s^{-2}

distance travelled $S = 25$ m.

(i) From equation of motion $v^2 = u^2 + 2aS$

$$v^2 = (0)^2 + 2 \times 0{\cdot}5 \times 25$$

or $v^2 = 25$

or Final velocity $v = \sqrt{25} = \mathbf{5 \text{ m s}^{-1}}$

(ii) From equation of motion $v = u + at$

$5 = 0 + 0{\cdot}5 \times t$ or $0{\cdot}5\, t = 5$

∴ Time taken $t = \dfrac{5}{0{\cdot}5} = \mathbf{10 \text{ s.}}$

5. A body moving with uniform acceleration travels 84 m in the first 6 s and 180 m in the next 5 s. Find : (a) the initial velocity, and (b) the acceleration of the body.

Let u be the initial velocity and a be the acceleration of the body.

Given, $S_1 = 84$ m, $t_1 = 6$ s,

$S_2 = 84 + 180 = 264$ m and $t_2 = 6 + 5 = 11$ s

From relation $S = ut + \frac{1}{2} at^2$

Distance travelled in 6 s,

$$84 = u \times 6 + \frac{1}{2} a \times (6)^2$$

or $6u + 18a = 84$ or $u + 3a = 14$ .... (i)

Distance travelled in 11 s,

$$264 = u \times 11 + \frac{1}{2} a \times (11)^2$$

or $11u + \frac{121}{2}a = 264$ or $u + \frac{11}{2}a = 24$ .... (ii)

On solving eqns. (i) and (ii),

Initial velocity of body $u = $ **2 m s⁻¹**

and acceleration $a = $ **4 m s⁻²**.

6. A body with an initial velocity of 18 km h⁻¹ accelerates uniformly at the rate of 9 cm s⁻² over a distance of 200 m. Calculate :

(i) the acceleration in m s⁻².

(ii) its final velocity in m s⁻¹.

(i) Acceleration $= 9 \text{ cm s}^{-2} = \frac{9}{100} \text{ m s}^{-2}$

$= \mathbf{0{\cdot}09 \text{ m s}^{-2}}$

(ii) Given, initial velocity $u = 18 \text{ km h}^{-1}$

$= \frac{18000 \text{ m}}{60 \times 60 \text{ s}} = 5 \text{ m s}^{-1}$

Acceleration $a = 0{\cdot}09 \text{ m s}^{-2}$ and distance $S = 200$ m

From equation of motion $v^2 = u^2 + 2aS$

$$v^2 = (5)^2 + 2 \times 0{\cdot}09 \times 200$$

or $$v^2 = 25 + 36 = 61$$

∴ Final velocity $v = \sqrt{61} = \mathbf{7{\cdot}81 \text{ m s}^{-1}}$.

7. A particle initially at rest, moves with an acceleration 5 m s⁻² for 5 s. Find the distance travelled in (a) 4 s, (b) 5 s and (c) 5th second.

Given, initial velocity $u = 0$,

acceleration $a = 5 \text{ m s}^{-2}$

(a) Distance travelled in $t = 4$ s,

$$S_1 = ut + \frac{1}{2}at^2 = 0 \times 4 + \frac{1}{2} \times 5 \times (4)^2$$

$= \mathbf{40 \text{ m}}$

(b) Distance travelled in $t = 5$ s,

$$S_2 = ut + \frac{1}{2}at^2 = 0 \times 5 + \frac{1}{2} \times 5 \times (5)^2$$

$= \mathbf{62{\cdot}5 \text{ m}}$

(c) Distance travelled in 5th second,

= Distance travelled in 5 s – Distance travelled in 4 s

$= S_2 - S_1 = (62{\cdot}5 - 40) \text{ m} = \mathbf{22{\cdot}5 \text{ m}}$

8. A particle starts to move in a straight line from a point with velocity 10 m s⁻¹ and acceleration – 2·0 m s⁻². Find the position and velocity of the particle at (i) $t = 5$ s, (ii) $t = 10$ s.

Given, $u = 10 \text{ m s}^{-1}$, $a = -2{\cdot}0 \text{ m s}^{-2}$

(i) Displacement at $t = 5$ s is

$$S = ut + \frac{1}{2}at^2$$

$$= 10 \times 5 + \frac{1}{2} \times (-2{\cdot}0) \times (5)^2$$

$$= 50 - 25 = 25 \text{ m}$$

i.e., after 5 s, the particle will be at distance **25 m** from the starting point.

Velocity at $t = 5$ s is

$$v = u + at$$

or $$v = 10 + (-2{\cdot}0) \times 5 = \mathbf{0}$$

i.e., the particle is momentarily at rest at $t = 5$ s.

(ii) Displacement at $t' = 10$ s is

$$S' = ut' + \frac{1}{2}at'^2$$

$$= 10 \times 10 + \frac{1}{2} \times (-2{\cdot}0) \times (10)^2$$

$$= 100 - 100 = 0 \text{ (zero)}$$

i.e., after 10 s, the particle has **come back to the starting point.**

Velocity at $t' = 10$ s is

$$v = u + at'$$

or $$v = 10 + (-2{\cdot}0) \times 10$$

$$= \mathbf{-10 \text{ m s}^{-1}}.$$

i.e., velocity is 10 m s⁻¹ towards the starting point (*i.e.*, opposite to the initial direction of motion).

EXERCISE 2(C)

1. Write *three* equations of uniformly accelerated motion relating the initial velocity (u), final velocity (v), time (t), acceleration (a) and displacement (S).
2. Derive following equations for a uniformly accelerated motion :

   (i) $v = u + at$

   (ii) $S = ut + \frac{1}{2}at^2$

   (iii) $v^2 = u^2 + 2aS$

   where the symbols have their usual meanings.
3. Write an expression for the distance S covered in time t by a body which is initially at

rest and starts moving with a constant acceleration a.

Ans. $S = \frac{1}{2}at^2$

Multiple choice type :

1. The correct equation of motion is :
   (a) $v = u + aS$ (b) $v = ut + a$
   (c) $S = ut + \frac{1}{2}at$ (d) $v = u + at$
   Ans. (d) $v = u + at$

2. A car starting from rest accelerates uniformly to acquire a speed 20 km h^{-1} in 30 min. The distance travelled by car in this time interval will be :
   (a) 600 km (b) 5 km
   (c) 6 km (d) 10 km **Ans.** (b) 5 km

Numericals :

1. A body starts from rest with a uniform acceleration 2 m s^{-2}. Find the distance covered by the body in 2 s. **Ans.** 4 m

2. A body starts with an initial velocity of 10 m s^{-1} and acceleration 5 m s^{-2}. Find the distance covered by it in 5 s. **Ans.** 112·5 m

3. A vehicle is accelerating on a straight road. Its velocity at any instant is 30 km h^{-1}, after 2 s, it is 33·6 km h^{-1} and after further 2 s, it is 37·2 km h^{-1}. Find the acceleration of vehicle in m s^{-2}. Is the acceleration uniform ?
   Ans. 0·5 m s^{-2}, Yes

4. A body, initially at rest, starts moving with a constant acceleration 2 m s^{-2}. Calculate : (i) the velocity acquired and (ii) the distance travelled in 5 s. **Ans.** (i) 10 m s^{-1}, (ii) 25 m

5. A bullet initially moving with a velocity 20 m s^{-1} strikes a target and comes to rest after penetrating a distance 10 cm in the target. Calculate the retardation caused by the target.
   Ans. 2000 m s^{-2}

6. A train moving with a velocity of 20 m s^{-1} is brought to rest by applying brakes in 5 s. Calculate the retardation. **Ans.** 4 m s^{-2}

7. A train travels with a speed of 60 km h^{-1} from station A to station B and then comes back with a speed 80 km h^{-1} from station B to station A. Find : (i) the average speed, and (ii) the average velocity of train.
   Ans. (i) 68·57 km h^{-1}, (ii) zero

8. A train is moving with a velocity of 90 km h^{-1}. It is brought to stop by applying the brakes which produce a retardation of 0·5 m s^{-2}. Find : (i) the velocity after 10 s, and (ii) the time taken by the train to come to rest.
   Ans. (i) 20 m s^{-1}, (ii) 50 s

9. A car travels a distance 100 m with a constant acceleration and average velocity of 20 m s^{-1}. The final velocity acquired by the car is 25 m s^{-1}. Find : (i) the initial velocity and (ii) acceleration of car. **Ans.** (i) 15 m s^{-1} (ii) 2 m s^{-2}

10. When brakes are applied to a bus, the retardation produced is 25 cm s^{-2} and the bus takes 20 s to stop. Calculate : (i) the initial velocity of bus, and (ii) the distance travelled by bus during this time. **Ans.** (i) 5 m s^{-1}, (ii) 50 m

11. A body moves from rest with a uniform acceleration and travels 270 m in 3 s. Find the velocity of the body at 10 s after the start.
    Ans. 600 m s^{-1}

12. A body moving with a constant acceleration travels the distances 3 m and 8 m respectively in 1 s and 2 s. Calculate : (i) the initial velocity, and (ii) the acceleration of body.
    Ans. (i) 2 m s^{-1}, (ii) 2 m s^{-2}

13. A car travels with a uniform velocity of 25 m s^{-1} for 5 s. The brakes are then applied and the car is uniformly retarded and comes to rest in further 10 s. Find : (i) the distance which the car travels before the brakes are applied, (ii) the retardation, and (iii) the distance travelled by the car after applying the brakes.
    Ans. (i) 125 m, (ii) 2·5 m s^{-2}, (iii) 125 m

14. A space craft flying in a straight course with a velocity of 75 km s^{-1} fires its rocket motors for 6·0 s. At the end of this time, its speed is 120 km s^{-1} in the same direction. Find : (i) the space craft's average acceleration while the motors were firing, (ii) the distance travelled by the space craft in the first 10 s after the rocket motors were started, the motors having been in action for only 6·0 s.
    Ans. (i) 7·5 km s^{-2}, (ii) 1065 km

15. A train starts from rest and accelerates uniformly at a rate of 2 m s^{-2} for 10 s. It then maintains a constant speed for 200 s. The brakes are then applied and the train is uniformly retarded and comes to rest in 50 s. Find : (i) the maximum velocity reached, (ii) the retardation in the last 50 s, (iii) the total distance travelled, and (iv) the average velocity of the train.
    Ans. (i) 20 m s^{-1}, (ii) 0·4 m s^{-2}, (iii) 4600 m, (iv) 17·69 m s^{-1}

3 LAWS OF MOTION

Syllabus :

(i) *Contact and non-contact forces; C.G.S. and S.I. units.*

Scope – Examples of contact forces (frictional force, normal reaction force, tension force as applied through strings and force exerted during collision) and non-contact forces (gravitational, electric and magnetic). General properties of non-contact forces. C.G.S. and S.I. units of force and their relation. Gravitational unit.

(ii) *Newton's first law of motion (qualitative discussion), introduction of the idea of inertia, mass and force.*

Scope – Newton's first law; statement and qualitative discussion, definitions of inertia and force from first law; examples of inertia as illustration of first law (Inertial mass not included).

(iii) *Newton's second law of motion (including $F = ma$); weight and mass.*

Scope – Detailed study of the second law. Linear momentum $p = mv$; change in momentum $\Delta p = \Delta(mv) = m\Delta v$ for mass remaining constant, rate of change of momentum $\Delta p/\Delta t = m\Delta v/\Delta t = ma$ $\left\{or\ \frac{p_2 - p_1}{t} = \frac{mv - mu}{t} = \frac{m(v-u)}{t} = ma\right\}$;

Simple numerical problems combining $F = \Delta p/\Delta t = ma$ and equations of motion. Units of force-only CGS and SI.

(iv) *Newton's third law of motion (qualitative discussion only), simple examples.*

Scope – Statement with qualitative discussion, examples of action-reaction pairs (F_{BA} and F_{AB}); action and reaction always act on different bodies.

(v) *Gravitation*

Scope – Universal law of gravitation (statement and equation) and its importance. Gravity, acceleration due to gravity, free fall, weight and mass, weight as force of gravity, comparison of mass and weight; gravitational units of force, simple numerical problems (problems on variation of gravity excluded).

(A) CONTACT AND NON-CONTACT FORCES

3.1 FORCE

We are familiar that a force when applied on a body can produce the following *two* main effects :

(1) *It can change the state of rest or of motion of the body i.e., it can produce motion in the body.*

Examples : The push exerted by a broom moves the trash. A ball lying on the ground moves when it is kicked. The pull exerted by a horse moves a cart. The pull exerted by a steam engine moves a train. The force due to gravity (or the earth's pull) makes an apple fall. A fielder on the ground stops a moving ball by applying force with his hands.

When force is applied on the pedal by a cyclist, the speed of the cycle increases. A freely falling object continuously gains speed due to the earth's pull acting along its direction of motion. The speed of a moving vehicle is slowed down by applying the brakes. A stone tied to one end of a string, whirling at a constant speed in a horizontal circle, changes its direction of motion continuously due to the force of tension in the string (which acts normal to the direction of motion of stone). In cricket, tennis and badminton, the direction of motion and the speed of the ball (or cock) is changed by hitting it in the direction other than its direction of motion. A player applies force with a hockey stick to change the speed and direction of motion of the ball.

(2) *It can change the size or shape of the body i.e., it can change the dimensions of the body.*

Examples : By loading a spring hanging from a rigid support, the length of the spring increases. By hammering a small piece of silver sheet, a big thin foil is made (here the force increases the surface area). The steam pushing out from a pressure cooker occupies a large volume in the atmosphere. On pressing a piece

of rubber, its shape changes. In a cycle pump, when the piston is lowered, the air is compressed to occupy a smaller volume.

Note : A force when applied on *a rigid object* does not change the inter-spacing between its constituent particles and therefore it does not change the dimensions of the object, but causes only the motion in it. On the other hand, a force when applied on a *non-rigid object,* changes the inter-spacing between its constituent particles and therefore causes a change in its dimensions and can also produce motion in it. Thus

> *A force is that physical cause which changes (or tends to change) either the size or the shape or the state of rest or of motion of the body.*

Kinds of forces : From the point of view of application, the forces are classified in *two* categories, namely, (i) the ***contact forces*** and (ii) the ***non-contact forces.***

3.2 CONTACT FORCES

The forces which are applied on bodies by making a physical contact, are called the contact forces.

These forces are produced and experienced when a body comes in *contact* with another body.

Examples : (1) The force of friction (frictional force), (2) normal reaction force, (3) Force of tension exerted by a string, (4) Force exerted by a spring, (5) Force exerted on two bodies during collision, etc.

(1) **Frictional force :** When a body slides (or rolls) over a rough surface, a force starts acting on the body in a direction *opposite* to the motion of the body, along the surface in contact. This is called the *frictional force* or the *force of friction.* In Fig. 3.1, when a book placed on the table top is pushed to the right, the force of friction acts on the book towards the left. This force *resists* the motion of the book on the table top.

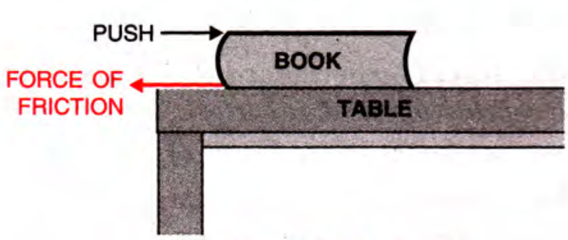


Fig. 3.1 Force of friction

(2) **Normal reaction force :** When a body is placed on a surface, the body exerts a force downwards, equal to its weight, on the surface, but the body does not move (or fall) because the surface exerts an equal and opposite force on the body normal to the surface which is called the *normal reaction force.* For example, in Fig. 3.2, when you hold a block on your palm, the block exerts a force due to its weight downwards on your palm and you have to exert a reaction force upwards on the block normal to the palm to keep the block in position. Similarly in Fig. 3.1, the book exerts a force (= weight) on the table top downwards and the table top exerts an equal reaction force upwards normal to the top of the table.

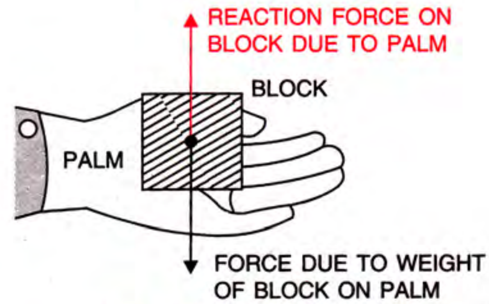


Fig. 3.2 Force of reaction

(3) **Tension force as applied through strings :** When a body is suspended by a string attached to a rigid support, the body, due to its weight *W*, pulls the string vertically downwards and the string in its stretched condition pulls the body upwards by a force which balances the weight of the body. This force developed in the string is called *tension* (or the force of tension) *T*. Fig. 3.3 shows the two forces which are equal and opposite in

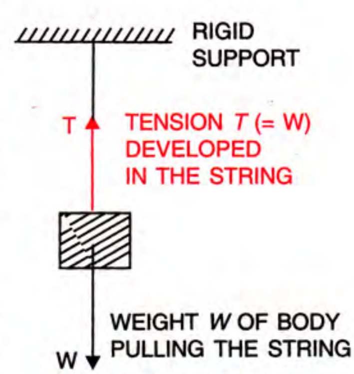


Fig. 3.3 Force of tension

equilibrium position. If we cut the string slightly above the body, we see that the string moves slightly upwards with a jerk due to tension in the string acting upwards and then falls downwards due to its own weight.

(4) **Force exerted by a spring :** Consider a spring with its one end kept fixed [Fig. 3.4(a)]. If its other end is either stretched [Fig. 3.4(b)] or compressed [Fig. 3.4(c)], the spring exerts a force F opposite to the direction of displacement of its free end, the magnitude of this force is directly proportional to the magnitude of displacement *i.e.*, its elongation or compression. This force is called *restoring force*. A spring-balance works on this principle.

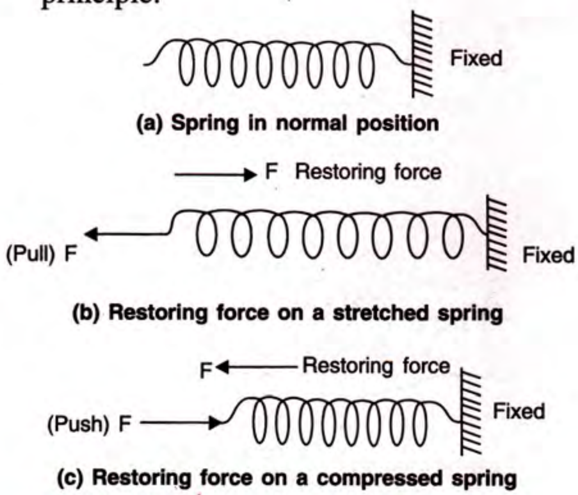


Fig. 3.4 Restoring force exerted by a spring

Similarly a horizontal spring with two objects A and B attached at its two ends in its normal form, does not exert any force on the object attached at its ends [Fig. 3.5(a)]. But if the spring is compressed, it *pushes away* each object with a restoring force F at its ends [Fig. 3.5(b)], while if the spring is stretched, it *pulls in* each object with a restoring force F at its ends [Fig. 3.5(c)]. In each case, the spring has a tendency to come back to its original form.

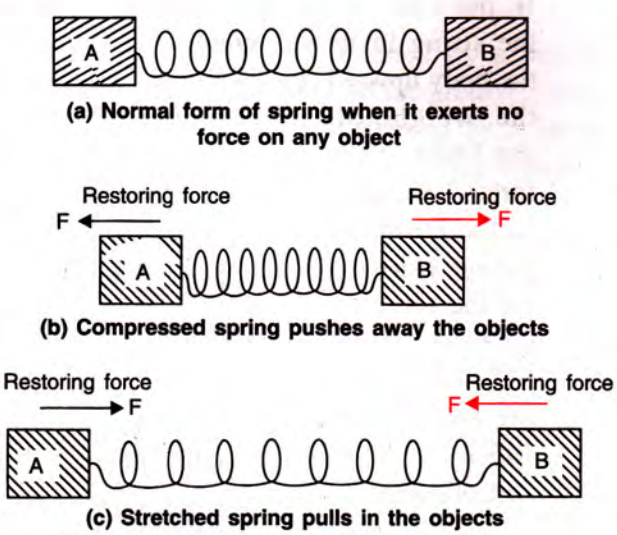


Fig. 3.5 Restoring force exerted by a spring

(5) **Force exerted during collision :** When two bodies collide, they push each other. As a result, equal and opposite forces act on each body. These forces are the force of action and force of reaction. In Fig. 3.6, a body B while in motion, collides with a moving body A and exerts a force F_{AB} on the body A which is called the force of action. *At the same instant*, the body A also exerts an equal and opposite force of reaction F_{BA} on the body B. As a result of these forces, the two bodies move apart after the collision.

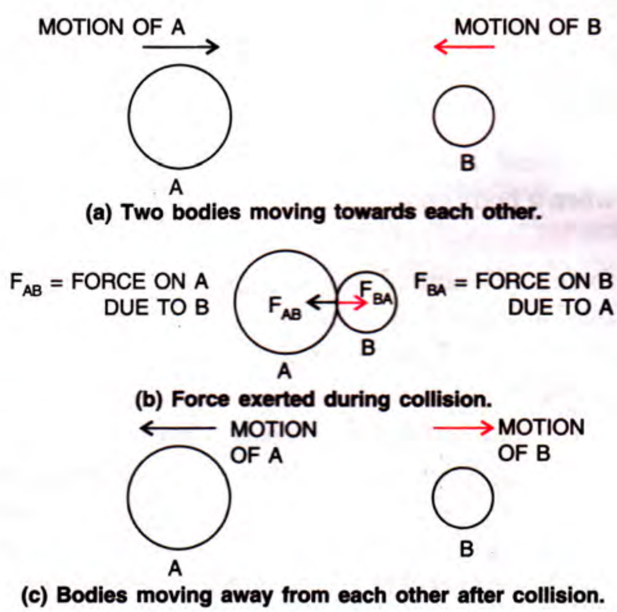


Fig. 3.6 Collision between two bodies

3.3 NON–CONTACT FORCES

The forces experienced by bodies even without being physically touched, are called the non-contact forces or the forces at a distance.

Examples : (1) Gravitational force, (2) Electrostatic force and (3) Magnetic force.

(1) **Gravitational force :** In universe, each particle attracts the other particle due to its mass. This force of attraction between them is called the *gravitational force*.

The earth also, because of its mass, attracts all other masses around it. The force on a body due to earth's attraction is called the *force of gravity* or the *weight of the body*. It causes motion in the body towards the earth (*i.e.*, downwards) if the body is free to move. Thus, it is the force due to gravity that makes a body fall, when released from a height. The body also attracts the earth by an equal force, but no motion is caused in the earth because of its huge mass.

Examples : (i) A ball placed on a table starts rolling down when the table is tilted.

(ii) If a body is thrown up in air, it goes up, reaches to a height and then returns to the ground.

(iii) A coin falls down when it is released at a height.

(2) **Electrostatic force :** Two like charges repel, while two unlike charges attract each other. The force between the charges is called the *electrostatic force*. This force acts between the charged objects even when they are separated.

Example : When a comb is rubbed on dry hairs, it gets charged. If this comb is brought near the small bits of paper, opposite charges are induced on the bits of paper and they begin to move towards the comb. The motion of paper bits is due to the electrostatic force of attraction exerted between the unlike charges on the comb and the paper bits.

(3) **Magnetic force :** Two like magnetic poles repel, while two unlike magnetic poles attract each other. The force between the magnetic poles is called the *magnetic force*. This force acts even when the magnetic poles are at a separation.

Example : When a pole of a magnet is brought near a small iron nail (without touching it), an opposite polarity is induced on the nail and it moves towards the magnet. The motion of nail is due to the magnetic force of attraction exerted between the unlike poles on the magnet and the nail.

General character of non-contact forces

(i) The gravitational force is always of attractive nature, while the electrostatic force and the magnetic force can be either attractive or repulsive.

(ii) *The magnitude of non-contact forces on the two bodies depends on the distance of separation between them. It decreases with the increase in separation and increases as the separation decreases.* It varies inversely as the square of distance of separation *i.e.*, on doubling the separation, the force becomes one-fourth.

EXERCISE 3(A)

1. Explain giving *two* examples each of :
   (a) Contact forces, and (b) Non-contact forces.
2. Classify the following amongst contact and non-contact forces :
   (a) frictional force,
   (b) normal reaction force,
   (c) force of tension in a string,
   (d) gravitational force,
   (e) electrostatic force,
   (f) magnetic force.
   Ans. Contact force : (a), (b) and (c),
   Non-contact force : (d), (e) and (f)
3. Give *one* example in each case where :
   (a) the force is of contact, and
   (b) force is at a distance.
4. (a) A ball is hanging by a string from the ceiling of the roof. Draw a neat labelled diagram showing the forces acting on the ball and the string.
   (b) A spring is compressed against a rigid wall. Draw a neat and labelled diagram showing the forces acting on the spring.
   (c) A wooden block is placed on a table top. Name the forces acting on the block and

draw a neat and labelled diagram to show the point of application and direction of these forces.

5. State *one* factor on which the magnitude of a non-contact force depends. How does it depend on the factor stated by you ?
Ans. Distance; Magnitude of force decreases as the distance increases

6. The separation between two masses is reduced to half. How is the magnitude of gravitational force between them affected ?
Ans. Force will become four times

7. State the effects of a force applied on (i) a non-rigid, and (ii) a rigid body. How does the effect of the force differ in the two cases ?

8. Give *one* example in each of the following cases where a force :
(a) stops a moving body.
(b) moves a stationary body.
(c) changes the size of a body.
(d) changes the shape of a body.

Multiple Choice Type

1. Which of the following is a contact force :
(a) electrostatic force (b) gravitational force
(c) frictional force (d) magnetic force.
Ans. (c) frictional force

2. The non-contact force is :
(a) force of reaction (b) force due to gravity
(c) tension in string (d) force of friction
Ans. (b) force due to gravity

(B) NEWTON'S FIRST LAW OF MOTION AND INERTIA

3.4 NEWTON'S FIRST LAW OF MOTION

In chapter 2, we have read the linear motion. Now the question arises : what is the cause of motion (*i.e.*, what produces motion in an object) ? It is our common experience that a force is to be applied on an object to produce motion in it.

Examples : To move a cycle, the cyclist has to apply force on its pedal. In a car, the petrol engine provides the force needed to move the car. To move a horse-cart, the horse applies force by stretching its muscles. To move a boat ahead, a force is applied by the oar on the water to push it backward and the force of reaction exerted by water moves the boat ahead.

Before Galileo, the scientists were of view that a force is needed not only to start a motion but also to keep an object moving even with uniform velocity. In other words, an object remains in motion so long as the external force applied to produce motion remains present (*i.e.*, a force must apply continuously to keep the body in motion). This view was based on the observation that the motion of a body ceases when force is withdrawn from it.

Examples : A cycle remains moving so long the force is applied on its pedal. If we stop pushing the pedal, the cycle stops. Similarly, if we put off the engine of a car, the car stops. The horse-cart stops after the horse stops moving and the boat stops after we stop pushing the oar.

Galileo did not approve the above view. From his experiments, he found that no force is needed to continue the motion of a moving body. If a body is set in motion, it will remain in motion even when the force applied to set the body in motion is withdrawn, *provided that there is no other force such as friction etc., to oppose the motion.* From our everyday life experience, we know that a cycle does not stop at once as we stop pedalling, but it moves a certain distance before coming to rest. In fact it stops due to the force of friction between its tyres and road, and also due to friction between its moving parts. If friction between its moving parts is reduced by proper oiling (or greasing) and it is made to move on a smooth road, it travels comparatively a much longer distance before coming to rest, after pedalling is stopped. If somehow it would have been possible to reduce the force of friction completely, the cycle would have remained in motion forever even when pedalling is stopped. Thus, it is concluded that in the absence of the force of friction, no force is required to keep an object moving after bringing it in motion. In other words, *an object, if once set in motion, moves with uniform velocity if no force acts on it.* Thus a body continues to be in the state of rest or in the state of uniform motion unless an external force is applied on it. This is called the *Galileo's law of inertia.*

From the above discussion, we note that

(i) *If a body is at rest, it remains at rest unless a force is applied on it.*

(ii) *If a body is moving, it will continue to move with the same speed in the same direction unless a force is applied on it.*

Newton put the above observations in the form of a law which is called the Newton's first law of motion.

Statement : According to Newton's first law of motion, if *a body is in a state of rest, it will remain in the state of rest and if it is in the state of motion, it will remain moving in the same direction with the same speed unless an external force is applied on it.*

Qualitative discussion

Newton's first law can be understood in the following *two* parts :

(i) definition of inertia, and

(ii) definition of force.

(i) ***Definition of inertia :*** In the first part, Newton's first law gives the definition of inertia, according to which *an object cannot change its state by itself.* If the object is in the state of rest, it will remain in the state of rest and if it is moving in some direction, it will continue to move with the same speed in the same direction unless an external force is applied on it.

Examples : A book lying on a table top will remain placed at its place unless it is displaced. Similarly, a ball rolling on a horizontal plane keeps on rolling unless the force of friction between the ball and the plane stops it.

*The property of an object by virtue of which it neither changes its state nor it tends to change the state, is called **inertia**.* It is the inherent property of each object.

(ii) ***Definition of force :*** The second part of Newton's first law defines the force, according to which *force is that external cause which can move a stationary object or which can change the state of motion of a moving object.*

Examples : A book lying on a table gets displaced from its place when it is pushed. A moving bicycle stops when a retarding force is applied by the brakes on its wheels.

Thus force is qualitatively defined as follows :

Force is that external cause which tends to change the state of rest or the state of motion of an object.

Note : (i) Force is a vector quantity. (ii) The sum of two equal and opposite forces is zero. (iii) A body acted upon by several forces can also have the resultant net force on it, equal to zero.

3.5 MASS AND INERTIA

Inertia is an inherent property of each body by virtue of which it has a tendency to resist the change in its state of rest or state of motion. The property of inertia is because of the mass of the body. *The greater the mass, the greater is the inertia of body.* Thus, a lighter body has less inertia than a heavier body. In other words, more the mass of a body, more difficult it is to move the body from rest (or to stop the body if it is initially in motion). Thus *mass is a measure of inertia.*

Examples : (1) A cricket ball is more massive than a tennis ball. The cricket ball acquires much smaller velocity than a tennis ball when the two balls are pushed with equal force for the same duration. In case when they are moving with the same velocity, it is more difficult to stop the cricket ball (which has more mass) in comparison to the tennis ball (which has less mass).

(2) It is difficult (*i.e.*, a larger force is required) to set a loaded trolley (which has more mass) in motion than an unloaded trolley (which has less mass). Similarly, it is difficult to stop a loaded trolley than an unloaded one, if both are moving initially with the same velocity.

3.6 KINDS OF INERTIA AND ITS EXAMPLES AS ILLUSTRATION OF FIRST LAW

Inertia is of the following *two* kinds :

(1) *Inertia of rest*, and (2) *Inertia of motion*.

(1) *Inertia of rest*

If a body is at rest, it will remain at rest unless an external force is applied to change its state of rest. This property of body is called the inertia of rest.

Examples :

(1) ***When a train suddenly starts moving forward, the passenger standing in the compartment tends to fall backwards :*** The reason is that the lower part of the passenger's body is in close contact with the train. As the train starts moving, his lower part shares the motion at once, but the upper part due to inertia of rest cannot share the motion simultaneously and so it tends to remain at the same place. Consequently, the lower part of the body moves ahead and the upper part is left behind, so the passenger tends to fall backwards.

(2) ***When a hanging carpet is beaten with a stick, the dust particles start falling out of it :*** The reason is that the part of the carpet where the stick strikes, comes in motion at once, while the dust particles settled on its fur, remain in position due to inertia of rest. Thus, the part of the carpet moves ahead with the stick, leaving behind the dust particles which fall down due to the earth's pull.

(3) ***On shaking (or giving jerks to) the branches of a tree, the fruits fall down :*** The reason is that when the stem (or branches) of the tree are shaken, they come in motion, while the fruits due to inertia, remain in the state of rest. Thus, the massive and weakly attached fruits get detached from the branches and fall down due to the pull of gravity.

(4) ***On striking the coin at the bottom of a pile of carrom coins with a striker, lowest coin only moves away, while the rest of the pile remains intact :*** The reason is that as the striker hits the lowest coin, it moves (*i.e.*, changes its state of rest), while the remaining pile due to inertia of rest remains where it is and ultimately takes the place of the original pile due to the force of gravity.

(5) ***When a smooth card placed over the mouth of a tumbler is flicked sharply in the horizontal direction, the card flies away, but the coin kept over the card falls into the tumbler :*** The reason is that when the card is flicked [Fig. 3.7(a)], a momentary force acts on the card, so it moves away [Fig. 3.7(b)]. But the

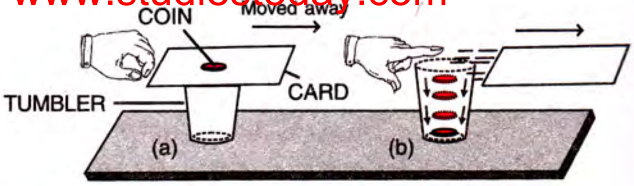


Fig. 3.7 Falling of coin kept on card

coin kept on it does not share the motion at once and it remains at its place due to inertia of rest. The coin then falls down into the tumbler due to the pull of gravity.

(6) ***When a corridor train suddenly starts, the sliding doors of some compartments may open :*** The reason is that the frame of sliding door being in contact with the floor of the train also comes in motion on start of the train, but the sliding door remains in its position due to inertia. Thus the frame moves ahead with the train while door slides opposite to the direction of motion of the train. Thus the door may open.

(2) *Inertia of motion*

A body in a state of motion, continues to be in the state of motion with the same speed in the same direction in a straight line unless an external force is applied on it to change its state. This property of body is called the inertia of motion.

Examples :

(1) ***A cyclist riding along a level road does not come to rest immediately after he stops pedalling :*** The reason is that the bicycle continues to move due to inertia of motion even after the cyclist stops applying the force on the pedal. The bicycle comes to rest afterwards as a result of the retarding force of friction between the tyres of bicycle and the ground.

(2) ***When a passenger jumps out of a moving train, he falls down :*** This is so because inside the train, his whole body was in a state of motion with the train. On jumping out of the moving train, as soon as his feet touch the ground, the lower part of his body comes to rest, while the upper part still remains in motion due to inertia of motion. As a result, he falls in the direction of motion of the train and gets hurt.

To avoid falling, as the passenger's feet touch the ground, he should start running on

ground in the direction of motion of the train for some distance.

(3) ***When a running car stops suddenly, the passenger tends to lean forward :*** The reason is that in a running car, the whole body of the passenger is in the state of motion. When the car stops suddenly, the lower part of his body, being in contact with the car, comes to rest immediately but his upper part remains in the state of motion, due to inertia. Thus his body leans forward.

(4) ***An athlete often runs before taking a long jump :*** The reason is that by running he brings his entire body in the state of motion. When the body is in motion, it becomes easier to take a long jump.

(5) ***A ball thrown vertically upwards by a person in a moving train comes back to his hand:*** The reason is that at the moment when ball was thrown, it was in motion alongwith the person and the train. It remains in the same state of forward motion even during the time the ball remains in air. The person, the inside air and the ball, all move ahead by the same distance due to inertia and so the ball falls back into his palm on its return.

EXERCISE 3(B)

1. Name the physical quantity which causes motion in a body. **Ans.** Force
2. Is force needed to keep a moving body in motion ? **Ans.** No
3. A ball moving on a table top eventually stops. Explain the reason.
   Ans. Force of friction between the ball and table top opposes the motion
4. A ball is moving on a perfectly smooth horizontal surface. If no force is applied on it, will its speed decrease, increase or remain unchanged ? **Ans.** will remain unchanged
5. What is the Galileo's law of inertia ?
6. State the Newton's first law of motion.
7. State and explain the law of inertia (or Newton's first law of motion).
8. What is meant by the term inertia ?
9. Give qualitative definition of force on the basis of Newton's first law of motion.
10. Name the factor on which inertia of a body depends and state how does it depend on the factor stated by you.
    Ans. Mass; more the mass, more is the inertia
11. Give *two* examples to show that greater the mass, greater is the inertia of the body.
12. 'More the mass, more difficult it is to move the body from rest'. Explain this statement by giving an example.
13. Name the *two* kinds of inertia.
14. Give *one* example of each of the following :
    (a) inertia of rest, and (b) inertia of motion.
15. Two equal and opposite forces act on a stationary body. Will the body move ? Give reason to your answer.
    Ans. No. Net force on the body is zero, so the body will remain stationary due to inertia of rest
16. Two equal and opposite forces act on a moving object. How is its motion affected ? Give reason.
    Ans. Motion remains unaffected.
    Reason : Net force on the object is zero.
17. An aeroplane is moving uniformly at a constant height under the action of *two* forces (i) upward force (lift) and (ii) downward force (weight). What is the net force on the aeroplane.
    Ans. Zero
18. Why does a person fall when he jumps out from a moving train ?
19. Why does a coin placed on a card, drop into the tumbler when the card is rapidly flicked with the finger ?
20. Why does a ball thrown vertically upwards in a moving train, come back to the thrower's hand ?
21. Explain the following :
    (a) When a train suddenly moves forward, the passenger standing in the compartment tends to fall backwards.
    (b) When a corridor train suddenly starts, the sliding doors of some compartments may open.
    (c) People often shake branches of a tree for getting down the fruits.
    (d) After alighting from a moving bus, one has to run for some distance in the direction of bus in order to avoid falling.
    (e) Dust particles are removed from a carpet by beating it.

(f) It is advantageous to run before taking a long jump.

Multiple choice type :

1. The property of inertia is more in :

   (a) a car (b) a truck

   (c) a horse cart (b) a toy car.

   Ans. (b) a truck

2. A tennis ball and a cricket ball, both are stationary. To start motion in them :

   (a) a less force is required for the cricket ball than for the tennis ball

   (b) a less force is required for the tennis ball than for the cricket ball

   (c) same force is required for both the balls

   (d) nothing can be said.

   Ans. (b) a less force is required for the tennis ball than for the cricket ball

3. A force is needed to :

   (a) change the state of motion or state of rest of the body

   (b) keep the body in motion

   (c) keep the body stationary

   (d) keep the velocity of body constant.

   Ans. (a) change the state of motion or state of rest of the body

(C) LINEAR MOMENTUM AND NEWTON'S SECOND LAW OF MOTION

3.7 LINEAR MOMENTUM ($p = mv$)

It is our common experience that if two bodies of different masses are moving with the same velocity and they are brought to rest in same time, the force needed to stop the heavier body is more than that for the lighter body. Similarly, if two bodies of the same mass are moving with different velocities, then to stop them in the same time, the force needed for the faster moving body is more than for the slower moving body. Thus, the *force needed to stop a moving body in a definite time depends both on the mass of the body and its velocity.* Actually the force needed to stop a moving body in a given time depends on the product of both the mass and velocity which is called the ***linear momentum*** of the moving body. Thus

Linear momentum of a body is the product of its mass and velocity.

The linear momentum of a body is denoted by the letter p. Generally the word momentum is used for linear momentum.

For a body of mass m moving with velocity v, linear momentum p is expressed as

$$\boxed{p = mv} \qquad \text{...(3.1)}$$

It is a **vector quantity** in the direction of motion of the body (*i.e.*, along the velocity of body).

Unit : From relation $p = mv$,

Unit of momentum = unit of mass × unit of velocity

Thus, the S.I. unit of momentum is kg m s^{-1} and the C.G.S. unit is g cm s^{-1}.

3.8 CHANGE IN MOMENTUM ($\Delta p = m\Delta v$)

From eqn. (3.1), change in momentum

$$\Delta p = \Delta(mv) \qquad \text{....(3.2)}$$

Here the symbol Δ (called del or delta) before a quantity denotes a small change in that quantity.

The change in product mv can be either due to change in mass m or due to change in velocity v or due to change in both the mass m and velocity v. If mass remains constant, then change in momentum is due to change in velocity v alone. Then from eqn. (3.2), for constant mass, change in momentum

$$\Delta p = \Delta(mv) = m\Delta v \qquad \text{....(3.3)*}$$

In case of atomic particles moving with velocity comparable to the velocity of light c (= 3×10^8 m s^{-1})**, it was observed that the mass of the particle does not remain constant, but it increases with increase in velocity, according to the relation $m = m_0 \sqrt{1-(v/c)^2}$ where m_0 is the mass of the particle when it is at rest (*i.e.*, $v = 0$). In such a case, we cannot write $\Delta(mv) = m\Delta v$. The relation $\Delta p = m\Delta v$ is true only if the velocity v of the

*** The symbol Δ before mv denotes a small change in the product of m and v. If mass m does not change, the product mv will change only due to change in v, and so m can be written before the symbol Δ. The quantity Δv now represents a small change in v only.**

**** c is the ultimate speed. No material particle can acquire a speed equal to or greater than c.**

moving particle is much smaller than the velocity of light c (or $v << c$). It happens when the velocity of particle is of the order of 10^6 m s^{-1} or less than this, then the variation in mass with velocity is small enough and mass can be considered to be constant. However the relation $\Delta p = \Delta(mv)$ is always true, whether mass m varies* or it remains constant.

3.9 RATE OF CHANGE OF MOMENTUM

When a force is applied on a moving body, its velocity changes. Due to change in velocity of the body, its momentum also changes.

Let a force F be applied on a body of mass m for time t due to which its velocity changes from u to v. Then

Initial momentum of the body = mu

Final momentum of the body = mv

Change in momentum of the body in t second

$$= mv - mu = m(v - u)$$

Rate of change of momentum

$$= \frac{\text{Change in momentum}}{\text{Time}} = \frac{m(v-u)}{t}$$

But acceleration $a = \dfrac{\text{Change in velocity}}{\text{Time}} = \dfrac{v-u}{t}$

$\therefore$ Rate of change of momentum = $m\,a$
= mass × acceleration

... (3.4)

This relation holds true when mass of the body remains constant.

Thus when a force acts on a body, the rate of change in momentum of body is equal to the product of mass of the body and acceleration produced in it due to that force, provided that the *mass of the body remains constant.*

Alternative method

For a body of mass m moving with velocity v, its linear momentum is $p = mv$. In time Δt, if its linear momentum changes by Δp on applying a force on it, then the rate of change of linear momentum is

$$\frac{\Delta p}{\Delta t} = \frac{\Delta(mv)}{\Delta t} = m\frac{\Delta v}{\Delta t} \text{ (if mass } m \text{ remains constant)}$$

But $\dfrac{\Delta v}{\Delta t} = a$ (acceleration),

so rate of change of momentum

$$\frac{\Delta p}{\Delta t} = ma = \text{mass} \times \text{acceleration.}$$

The above eqn. is same as eqn. (3.4).

3.10 NEWTON'S SECOND LAW OF MOTION (DERIVATION OF $F = ma$)

Newton's first law of motion defines the force only qualitatively. A force changes the state of motion of a body when it is applied on it. It means that *the force produces acceleration in the body i.e.*, the force is the cause of acceleration. Now we shall see that the Newton's second law of motion gives the quantitative value of force, *i.e.*, it relates force to the measurable quantities like acceleration and mass.

It is our common experience that if we push a tennis ball gently, a small acceleration is produced and it acquires a small velocity in a certain time, but if the same tennis ball is pushed hard, a larger acceleration is produced in it and it acquires a large velocity in the same time interval. Thus the magnitude of two forces can be compared by measuring the accelerations produced by them when they are applied one by one on the same body. If a force F_1 produces an acceleration of 5 m s^{-2} and a force F_2 produces an acceleration of 10 m s^{-2} on the same body, then the magnitude of force F_2 is two times the magnitude of force F_1. Experimentally Newton found that *the acceleration produced in a body is directly proportional to the force applied on it.*

Similarly if we try to produce same change in velocity in the same time (*i.e.*, to produce same acceleration) in a football and a tennis ball, initially both at rest, we need to apply a large force on the football than on the tennis ball. Thus the force needed to produce same acceleration in two bodies of different masses is not same. It is more for the body of larger mass and less for the body of smaller mass. If a force F is needed to produce an acceleration of 5 m s^{-2} in a body of mass 2 kg, then to produce same acceleration (= 5 m s^{-2}) in a body of mass 4 kg, the force needed is of double the magnitude *i.e.* $2F$. Experimentally Newton found that the *force needed to produce same acceleration in different bodies is proportional to their masses.*

*** For example in rocket motion, the mass of rocket decreases as the burnt gases expel out of the nozzle, so the mass does not remain constant.**

On the basis of his experiments, Newton concluded that

(i) *The acceleration produced in a body of given mass is directly proportional to the force applied on it. i.e.,*

$a \propto F$ (if mass remains constant) ...(3.5)

A graph plotted for acceleration a against force F is a straight line as shown in Fig. 3.8.

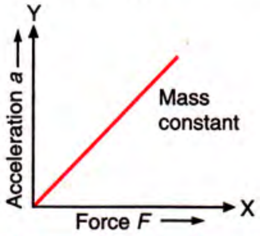


Fig. 3.8 Graph showing the variation of acceleration with force

(ii) *The force needed to produce a given acceleration in a body is directly proportional to the mass of the body. i.e.,*

$F \propto m$ (if acceleration remains the same) ...(3.6)

A graph plotted for force F against mass m is a straight line as shown in Fig. 3.9.

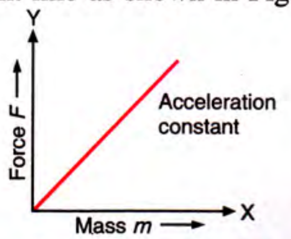


Fig. 3.9 Graph showing the variation of force with mass

Combining eqns. (3.5) and (3.6),

$$\boxed{F = K m a} \quad ...(3.7)$$

Here K is a constant. The unit of force is so chosen that K becomes 1, when $m = 1$ and $a = 1$. Thus, that amount of force is taken as one unit of force which when applied on a body of unit mass, produces a unit acceleration in the body.

With the unit of force so choosen, eqn. (3.7) takes the following form :

$$F = m \times a$$

or $$\text{force} = \text{mass} \times \text{acceleration} \quad ...(3.8)$$

This is the mathematical expression of Newton's second law of motion.

Note : If a given force is applied on bodies of different masses, the acceleration produced in them is inversely proportional to their masses *i.e.*, $a \propto \frac{1}{m}$ (for a given force F). A graph plotted for acceleration a against mass m is a curve (hyperbola) as shown in Fig. 3.10.

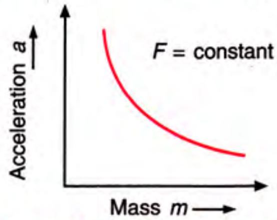


Fig. 3.10 Graph showing the variation of acceleration with mass

3.11 C.G.S. AND S.I. UNITS OF FORCE

The force is related to mass and acceleration as :

$$\text{Force} = \text{mass} \times \text{acceleration}$$

or $$F = m\,a$$

On this basis, *the S.I. unit of force is* **newton**.

One newton is the force which when acts on a body of mass 1 kg, *produces an acceleration of* 1 m s^{-2}. *i.e.,* **1 newton = 1 kg × 1 m s^{-2}**

The standard symbol of newton is N.

In C.G.S. system, the unit of force is **dyne**.

One dyne is the force which when acts on a body of mass 1 g, *produces an acceleration of* 1 cm s^{-2}. *i.e.,* **1 dyne = 1 g × 1 cm s^{-2}**

Relationship between newton and dyne

$$\begin{aligned} 1 \text{ newton} &= 1 \text{ kg} \times 1 \text{ m s}^{-2} \\ &= 1000 \text{ g} \times 100 \text{ cm s}^{-2} = 10^5 \text{ g} \times \text{cm s}^{-2} \\ &= 10^5 \text{ dyne.} \end{aligned}$$

Thus $$\boxed{1 \text{ newton} = 10^5 \text{ dyne}} \quad .... (3.9)$$

3.12 NEWTON'S SECOND LAW OF MOTION IN TERMS OF RATE OF CHANGE OF MOMENTUM

When force is applied on a body, it produces acceleration in the body due to which the velocity and hence the momentum of body changes.

From eqn. (3.4), the rate of change of momentum is equal to the product of mass and acceleration *i.e.*,

$$\frac{\Delta p}{\Delta t} = ma \text{ (if mass remains constant).}$$

From eqn. (3.8), by Newton's second law of motion, force $F = ma$.

$\therefore$ Force = Rate of change of momentum

or $$F = \frac{\Delta p}{\Delta t} = \frac{\Delta(mv)}{\Delta t}$$
$$= ma \text{ (if mass remains constant)} \quad ...(3.10)$$

Thus Newton's second law of motion can be stated in terms of change in momentum as follows.

Statement : According to Newton's second law of motion, *the rate of change of momentum of a body is directly proportional to the force applied on it and the change in momentum takes place in the direction in which the force is applied.*

Explanation

According to Newton's second law of motion, $F = \frac{\Delta p}{\Delta t} = \frac{\Delta(mv)}{\Delta t}$. This is the general form of Newton's second law of motion when the momentum changes either due to change in mass or due to change in velocity or due to change in both the mass and velocity.

It is observed that the mass of a particle increases with increase in velocity but it becomes perciptible only when the velocity v of the particle is comparable with the speed of light c (3×10^8 m s^{-1}). At velocities $v << c$ (*i.e.*, when $v << 10^6$ m s^{-1}), the change in mass is not perceptible*. At such velocities ($v << c$), mass m can be considered to be constant. Then Newton's second law takes the form $F = m\frac{\Delta v}{\Delta t} = ma$.

Thus, for the relation $F = m\frac{\Delta v}{\Delta t} = ma$ *to hold, two conditions are needed : (i) when velocities are much smaller than the velocity of light, and (ii) when mass remains constant.*

Newton's second law is the fundamental law of motion. The first law of motion is also included in the second law. This we can see as follows.

To obtain Newton's first law of motion from second law of motion

From Newton's second law, $F = m\,a$

If $F = 0$, then $a = 0$

This means that if no force is applied on the body, its acceleration will be zero. If the body is at rest, it will remain at rest and if it is moving, it will remain moving in the same direction with the same speed. Thus *a body not acted upon by any external force, does not change its state of rest or of motion.* This is the statement of Newton's first law of motion.

* When $v = 10^6$ m s^{-1}, $m = 1{\cdot}0000056\ m_0$ and when $v = 10^7$ m s^{-1}, $m = 1{\cdot}0005561\ m_0$. Here m_0 is the mass at $v = 0$.

Examples of second law of motion in daily life

The mathematical expression of the second law of motion is $F = \Delta p/\Delta t$. It gives $\Delta p = F\Delta t$, so a given change in momentum of a body can be brought about either by applying a large force for a small duration or by applying a small force for a long duration. For example, in hitting a cricket ball by a bat, hammering a nail, hitting the ping-pong ball by a racket, *etc.* a required momentum is imparted to the body by applying a force of large magnitude for a short duration. On the other hand in the following examples the momentum of a moving body is brought to zero in a large duration so as to reduce the effect of force exerted by the moving body.

Examples :

(1) While catching a ball, the cricketer withdraws his hands along with the ball

Let u be the velocity of the ball of mass m when it reaches the hands of the player catching it.

The initial momentum of ball = $m\,u$

When the cricketer stops the ball ($v = 0$), its final momentum = $m \times 0 = 0$.

Change in momentum

= final momentum – initial momentum

= $0 - mu = -\,mu = mu$ (numerically)

Here –ve sign shows that the change in momentum is in direction opposite to the initial direction of motion.

If the cricketer does not pull back his hands and stops the ball as soon it touches his hands, he gets very little time t_1 to stop the ball. Then the force exerted by the ball on the hands of the cricketer is $F_1 = \frac{\text{Change in momentum}}{\text{Time interval}} = \frac{mu}{t_1}$. But if the cricketer pulls back his hands along with the ball, he takes a longer time t_2 to stop the ball. The force now exerted by the ball on his hands is $F_2 = \frac{mu}{t_2}$. Since $t_2 > t_1$, therefore $F_2 < F_1$ or the force exerted on the hands of cricketer by the fast moving ball is less when he withdraws his hands. Thus cricketer avoids the chances of injury to his palms by withdrawing his hands alongwith the moving ball while catching it.

(2) Athletes often lands on sand (or foam) after taking a high jump

When an athlete lands from a height on a

hard floor, he may hurt his feet because his feet come to rest almost instantenously (*i.e.*, in a very short interval of time), so a very large force is exerted by the floor on his feet. On the other hand, when he lands on sand (or foam), his feet push the sand (or foam) for some distance, therefore the time duration in which his feet come to rest, increases. As a result, the force exerted on his feet decreases and he is saved from getting hurt.

(3) When the glass vessels fall on a hard floor, they break, but they do not break when they fall on a carpet (or sand)

When a glass vessel falls from a height on a hard floor, it comes to rest almost instantenously (*i.e.*, in a very short time) so the floor exerts a large force on the vessel and it breaks. But if it falls on a carpet (or sand), the time duration in which the vessel comes to rest, increases and so the carpet (or sand) exerts a less force on the vessel and it does not break.

EXAMPLES

1. How much force is required to produce an acceleration of 2 m s^{-2} in a body of mass 0·8 kg ?

Given, m = 0·8 kg, a = 2 m s^{-1}

Force $F = m\,a$

= 0·8 kg × 2 m s^{-2}

= **1·6 newton** (or **1·6 N**).

2. A force acts for 0·1 s on a body of mass 1·2 kg initially at rest. The force then ceases to act and the body moves through 2 m in the next 1·0 s. Find the magnitude of force.

When force ceases to act, the body will move with a constant velocity. Since it moves a distance 2 m in 1·0 s, therefore its uniform velocity is 2 m s^{-1}. Thus under the influence of force, the body acquires a velocity 2 m s^{-1} in 0·1 s.

i.e., $u = 0$, v = 2 m s^{-1}, t = 0·1 s and m = 1·2 kg

Now acceleration $a = \dfrac{\text{Change in velocity}}{\text{Time}}$

or $a = \dfrac{v-u}{t} = \dfrac{(2-0)\text{ m s}^{-1}}{0{\cdot}1\text{ s}}$

= 20 m s^{-2}

From the relation $F = ma$,

Force F = 1·2 kg × 20 m s^{-2} = **24 N**

3. A ball of mass 10 g is moving with a velocity of 50 m s^{-1}. On applying a constant force on ball for 2·0 s, it acquires a velocity of 70 m s^{-1}. Calculate :

(i) the initial momentum of ball,

(ii) the final momentum of ball,

(iii) the rate of change of momentum,

(iv) the acceleration of ball, and

(v) the magnitude of force applied.

Given, $m = 10\text{ g} = \dfrac{10}{1000}$ kg = 0·01 kg, u = 50 m s^{-1},

t = 2·0 s, v = 70 m s^{-1}.

(i) Initial momentum of ball = mass × initial velocity

= mu

= 0·01 kg × 50 m s^{-1}

= **0·5 kg m s^{-1}**

(ii) Final momentum of the ball = mass × final velocity

= mv

= 0·01 kg × 70 m s^{-1}

= **0·7 kg m s^{-1}**

(iii) Rate of change of momentum

$= \dfrac{\text{Final momentum} - \text{Initial momentum}}{\text{Time interval}}$

$= \dfrac{(0{\cdot}7 - 0{\cdot}5)\text{ kg m s}^{-1}}{2{\cdot}0\text{ s}}$ = 0·1 kg m s^{-2} (or **0·1 N**)

(iv) Acceleration $a = \dfrac{v-u}{t} = \dfrac{(70-50)\text{ m s}^{-1}}{2\text{ s}}$ = **10 m s^{-2}**

(v) Force = mass × acceleration

= ma

= 0·01 kg × 10 m s^{-2} = **0·1 N**

4. A cricket ball of mass 100 g moving with a speed of 30 m s^{-1} is brought to rest by a player in 0·03 s. Find :

(i) the change in momentum of ball,

(ii) the average force applied by the player.

Given, $m = 100\text{ g} = \dfrac{100}{1000}$ kg = 0·1 kg, u = 30 m s^{-1},

$v = 0$, t = 0·03 s.

(i) Initial momentum = mu

= 0·1 × 30 = 3·0 kg m s^{-1}

Final momentum = mv

= 0·1 × 0 = 0

Change in momentum = Final momentum – Initial momentum

= 0 – 3·0 = **– 3·0 kg m s^{-1}**

(ii) Average force

$F = \dfrac{\text{Change in momentum}}{\text{Time } t} = \dfrac{-3{\cdot}0\text{ kg m s}^{-1}}{0{\cdot}03\text{ s}}$

= **– 100 N**

(Negative sign here shows that the force is applied in a direction opposite to the direction of motion of ball).

EXERCISE 3(C)

1. Name the *two* factors on which the force needed to stop a moving body in a given time, depends.
2. Define linear momentum and state its S.I. unit.
3. A body of mass m moving with a velocity v is acted upon by a force. Write expression for change in momentum in each of the following cases : (i) when $v << c$, (ii) when $v \to c$, and (iii) when $v << c$ but m does not remain constant. Here c is the speed of light.
   Ans. (i) $m\,\Delta v$ (ii) $\Delta(mv)$ (iii) $\Delta(mv)$
4. Show that the rate of change of momentum = mass × acceleration. Under what condition does this relation hold ?
5. Two bodies A and B of same mass are moving with velocities v and $2v$ respectively. Compare their (i) inertia, (ii) momentum.
   Ans. (i) 1 : 1 (ii) 1 : 2
6. Two balls A and B of masses m and $2m$ are in motion with velocities $2v$ and v respectively. Compare : (i) their inertia, (ii) their momentum, and (iii) the force needed to stop them in the same time. **Ans.** (i) 1 : 2 (ii) 1 : 1 (iii) 1 : 1
7. State Newton's second law of motion. What information do you get from it ?
8. How does Newton's second law of motion differ from first law of motion ?
9. Write the mathematical form of Newton's second law of motion. State condition if any.
10. State Newton's second law of motion. Under what condition does it take the form $F = ma$?
11. How can Newton's first law of motion be obtained from the second law of motion ?
12. Draw graphs to show the dependence of (i) acceleration on force for a constant mass, and (ii) force on mass for a constant acceleration.
13. How does the acceleration produced by a given force depend on mass of the body ? Draw graph to show it.
14. Name the S.I. unit of force and define it.
15. What is the C.G.S. unit of force ? How is it defined ?
16. Name the S.I. and C.G.S. units of force. How are they related ?
17. Why does a glass vessel break when it falls on a hard floor, but it does not break when it falls on a carpet ?
18. Use Newton's second law of motion to explain the following :
    (a) A cricketer pulls his hands back while catching a fast moving cricket ball.
    (b) An athlete prefers to land on sand instead of hard floor while taking a high jump.

Multiple choice type :

1. The linear momentum of a body of mass m moving with velocity v is :
   (a) v/m (b) m/v
   (c) mv (d) $1/mv$ **Ans.** (c) mv
2. The unit of linear momentum is :
   (a) N s (b) kg m s^{-2}
   (c) N s^{-1} (d) kg^2 m s^{-1} **Ans.** (a) N s
3. The correct form of Newton's second law is :
   (a) $F = \dfrac{\Delta p}{\Delta t}$ (b) $F = m\dfrac{\Delta v}{\Delta t}$
   (c) $F = v\dfrac{\Delta m}{\Delta t}$ (d) $F = mv$ **Ans.** (a) $F = \dfrac{\Delta p}{\Delta t}$
4. The acceleration produced in a body by a force of given magnitude depends on
   (a) size of the body (b) shape of the body
   (c) mass of the body (d) none of these.
   Ans. (c) mass of the body

Numericals :

1. A body of mass 5 kg is moving with velocity 2 m s^{-1}. Calculate its linear momentum.
   Ans. 10 kg m s^{-1}
2. The linear momentum of a ball of mass 50 g is 0·5 kg m s^{-1}. Find its velocity. **Ans.** 10 m s^{-1}
3. A force of 15 N acts on a body of mass 2 kg. Calculate the acceleration produced.
   Ans. 7·5 m s^{-2}
4. A force of 10 N acts on a body of mass 5 kg. Find the acceleration produced. **Ans.** 2 m s^{-2}
5. Calculate the magnitude of force which when applied on a body of mass 0·5 kg produces an acceleration of 5 m s^{-2}. **Ans.** 2·5 N
6. A force of 10 N acts on a body of mass 2 kg for 3 s, initially at rest. Calculate : (i) the velocity acquired by the body, and (ii) change in momentum of the body.
   Ans. (i) 15 m s^{-1}, (ii) 30 kg m s^{-1}.
7. A force acts for 10 s on a stationary body of mass 100 kg after which the force ceases to act. The body moves through a distance of 100 m in the next 5 s. Calculate : (i) the velocity

acquired by the body, (ii) the acceleration produced by the force, and (iii) the magnitude of the force.

Ans. (i) 20 m s^{-1}, (ii) 2 m s^{-2}, (iii) 200 N

8. Fig. 3.11 shows the velocity-time graph of a particle of mass 100 g moving in a straight line. Calculate the force acting on the particle.

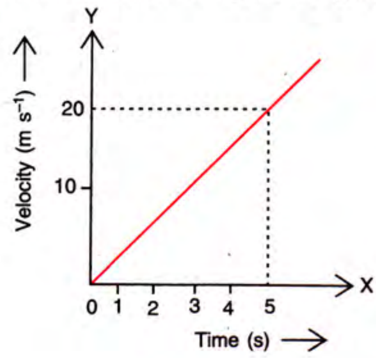


Fig. 3.11

(**Hint :** Acceleration = slope of v–t graph)

Ans. 0·4 N

9. A force acts for 0·1 s on a body of mass 2·0 kg initially at rest. The force is then withdrawn and the body moves with a velocity of 2 m s^{-1}. Find the magnitude of force. **Ans.** 40 N

10. A cricket ball of mass 100 g moving at a speed of 30 m s^{-1} is brought to rest by a player in 0·03 s. Find the average force applied by the player. **Ans.** 100 N

11. A car of mass 480 kg moving at a speed of 54 km h^{-1}, is stopped by applying breaks in 10 s. Calculate the force applied by the brakes. **Ans.** 720 N

12. A bullet of mass 50 g moving with an initial velocity 100 m s^{-1}, strikes a wooden block and comes to rest after penetrating a distance 2 cm in it. Calculate : (i) initial momentum of the bullet, (ii) final momentum of the bullet, (iii) retardation caused by the wooden block, and (iv) resistive force exerted by the wooden block

Ans. (i) 5 kg m s^{-1}, (ii) zero, (iii) $2{\cdot}5 \times 10^5$ m s^{-2}, (iv) 12500 N

13. A force causes an acceleration of 10 m s^{-2} in a body of mass 500 g. What acceleration will be caused by the same force in a body of mass 5 kg ? **Ans.** 1 m s^{-2}

14. A car is moving with a uniform velocity 30 m s^{-1}. It is stopped in 2 s by applying a force of 1500 N through its brakes. Calculate : (a) the change in momentum of car, (b) the retardation produced in car, and (c) the mass of car.

Ans. (a) 3000 kg m s^{-1} (b) 15 m s^{-2} (c) 100 kg

(D) NEWTON'S THIRD LAW OF MOTION

3.13 NEWTON'S THIRD LAW OF MOTION

Newton's first law tells us that to bring a change in the state of rest or in the state of motion of an object, a force is needed *i.e.*, a force produces a change in velocity of the object. Newton's second law tells us the magnitude of acceleration produced by the force when applied on the object. These two laws do not explain how does the force act on the object ? This question is answered by the Newton's third law, which is stated as follows.

Statement : According to Newton's third law of motion, *to every action there is always an equal and opposite reaction.*

Examples :

(i) Consider a book lying on a table. The weight of the book acts vertically downwards, but the book does not move downwards. It implies that the resultant force on the book is zero, which is possible only if the table exerts an equal upward force on the book equal to the weight of the book. This force on the book balances the weight of the book.

(ii) While moving on the ground, we exert a force by our feet to push the ground backwards, the ground exerts a force of the same magnitude on our feet forward which makes us to move forward.

Explanation : In the above stated examples, we observe that there are two objects and two forces. In the first example, the weight of the book acting on the table downwards is the *force of action* and the force exerted by table on the book upwards is the *force of reaction*. In the second example, the force exerted by our feet on the ground is the *force of action* and the force exerted by the ground on our feet is the *force of reaction*.

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Thus Newton's third law of motion states :

In an interaction of two bodies A and B, the magnitude of reaction (i.e., the force F_{AB} applied by the body B on the body A) is equal in magnitude to the action (i.e., the force F_{BA} applied by the body A on the body B), but they are in directions opposite to each other.

Note : The action and reaction never act on the same body, but they always act *simultaneously* on two different bodies *i.e., the forces of interaction are always present in a pair.*

Experimental demonstration of Newton's third law

Experiment : In Fig. 3.12, the ring of a spring balance *B* is attached to a hook fixed in a wall, and then the hook of another spring balance *A* is attached to the hook of the spring balance *B*. Now the ring of spring balance *A* is pulled. We find that *both the balances show the same reading.*

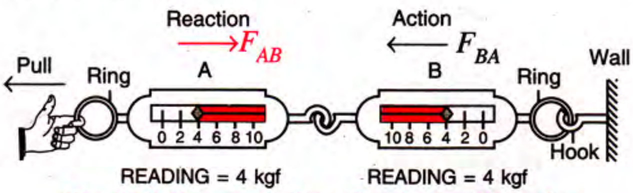

Fig. 3.12 Demonstration of action and reaction

Explanation : The spring of balance *A* pulls the spring of balance *B* due to which we get some reading in balance *B*. The same reading is seen in balance *A* because the spring of balance *B* also pulls the spring of balance *A* by the same force. The pull on the spring *B* by the spring *A* is the *action* F_{BA} and the pull on the spring *A* by the spring *B* is the reaction F_{AB}. This demonstrates that "to every action, there is an equal and opposite reaction" (*i.e.*, in magnitude $F_{AB} = F_{BA}$ but they are in opposite directions) or $\vec{F}_{AB} = -\vec{F}_{BA}$. .....(3.11)

Examples of action and reaction

(1) ***A book on a table :*** When a book is placed on a table top, the book exerts a force equal to its weight *W* (*action*) on the table in direction $\vec{AB}$ downwards and the table balances it by an equal force called the *reaction* *R* ($R = W$) acting upwards on the book in direction $\vec{AD}$. Fig. 3.13 shows these action and reaction.

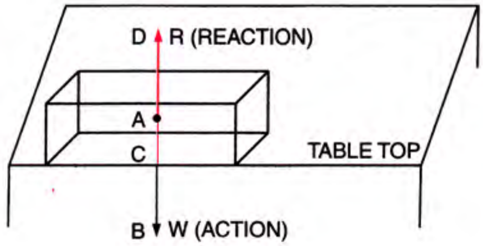

Fig. 3.13 Action and reaction on a book lying on a table

(2) ***Pushing a wall :*** When you exert a force (*action*) on a wall by pushing the palm of your hand against it, you experience a force (*reaction*) exerted by the wall on your palm.

(3) ***Motion of a boat moving away from the shore:*** When a boatman wants to move the boat away from the shore, he pushes the shore by a bamboo or with his oar (*action*). The shore pushes the boatman (along with boat) away with an equal and opposite force (*reaction*).

(4) ***Motion of boat in water :*** To move a boat ahead in water, the boatman pushes (*action*) the water backwards with his oar and the water exerts an equal and opposite force (*reaction*) in the forward direction on the boat due to which the boat moves ahead.

(5) ***Firing a bullet from a gun :*** When a man fires a bullet from a gun, a force *F* is exerted on the bullet (*action*) and the gun experiences an *equal* recoil *R* (*reaction*) as shown in Fig. 3.14.

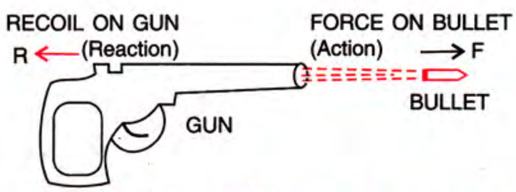

Fig. 3.14 Action and reaction on firing a bullet from a gun

(6) ***Rocket motion :*** In a rocket, fuel is burnt inside the rocket and the burnt gases at high pressure and high temperature are expelled out of the rocket through a nozzle. Thus, rocket exerts a force *F* (*action*) on gases to expel them through a nozzle backwards. The outgoing gases exert an equal and opposite force *R* (*reaction*) on the rocket due to which it moves in the forward direction (Fig. 3.15).

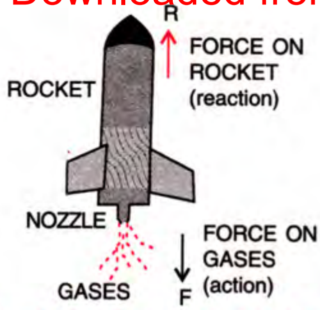

Fig. 3.15 Action and reaction in rocket motion

(7) ***Motion of man on ground :*** When a man applies a force F (*action*) backward by his foot on the ground against the force of friction, the ground exerts an equal and opposite force R (*reaction*) forward on his foot. The horizontal component of the force of reaction R enables the man to move forward (Fig. 3.16). Obviously it will be difficult for a man to move on a slippery road where friction is less.

Fig. 3.16 Action and reaction while a man moves on ground

(8) ***Motion of boat away from the shore while stepping down from it :*** When a man exerts a force (*action*) on the boat, its force of *reaction* enables him to step out of the boat. At the same instant, the boat tends to leave the shore due to the force exerted by the man (*i.e.*, action).

(9) ***Catching a ball :*** While catching a ball, the ball exerts a force (*action*) on the hand of cricketer and the cricketer exerts an equal force (*reaction*) on the ball to stop it.

EXERCISE 3(D)

1. State the usefulness of Newton's third law of motion.
2. State Newton's third law of motion.
3. State and explain the law of action and reaction, by giving *two* examples.
4. Name and state the action and reaction in the following cases :
   (a) firing a bullet from a gun,
   (b) hammering a nail,
   (c) a book lying on a table,
   (d) a moving rocket,
   (e) a person walking on the floor,
   (f) a moving train colliding with a stationary train.
5. Explain the motion of a rocket with the help of Newton's third law.
6. When a shot is fired from a gun, the gun gets recoiled. Explain.
7. When you step ashore from a stationary boat, it tends to leave the shore. Explain.
8. When two spring balances joined at their free ends, are pulled apart, both show the same reading. Explain.
9. To move a boat ahead in water, the boatman has to push the water backwards by his oar. Explain.
10. A person pushing a wall hard is liable to fall back. Give reason.
11. 'The action and reaction both act simultaneously.' Is this statement true ? **Ans.** Yes
12. 'The action and reaction are equal in magnitude'. Is this statement true ? **Ans.** Yes
13. A light ball falling on ground, after striking the ground rises upwards. Explain the reason.
14. Comment on the statement 'the sum of action and reaction on a body is zero'.
    [**Hint :** The statement is wrong]

Multiple choice type :

1. Newton's third law :
   (a) defines the force qualitatively
   (b) defines the force quantitatively
   (c) explains the way the force acts on a body
   (d) gives the direction of force.
   Ans. (c) explains the way the force acts on a body
2. Action and reaction act on the :
   (a) same body in opposite directions
   (b) different bodies in opposite directions
   (c) different bodies, but in same direction
   (d) same body in same direction.
   Ans. (b) different bodies in opposite directions

Numericals :

1. A boy pushes a wall with a force of 10 N towards east. What force is exerted by the wall on the boy ? **Ans.** 10 N towards west
2. In Fig. 3.17, a block of weight 15 N is hanging from a rigid support by a string. What force is exerted by
   (a) block on the string,
   (b) string on the block.
   Name them and show them in the diagram.

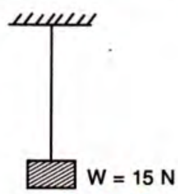

Fig. 3.17

   Ans. (a) 15 N downwards (weight), (b) 15 N upwards (tension)

(E) GRAVITATION

3.14 UNIVERSAL LAW OF GRAVITATION

Each mass particle of the universe attracts the other mass particle. The force of attraction between the two particles because of their masses, is called the *gravitational force of attraction*. For the magnitude of this force, Sir Issac Newton gave a law, known as *Newton's law of gravitation.*

According to Newton, *the force of attraction acting between the two particles is (i) directly proportional to the product of their masses and (ii) inversely proportional to the square of the distance between them.* This force acts along the line joining the two particles.

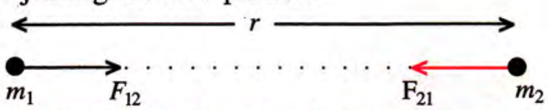

Fig. 3.18 Gravitational force between two particles

In Fig. 3.18, let there be two particles of masses m_1 and m_2 at a separation r. The magnitude of force of attraction F acting between them is

$$F \propto m_1 m_2 \text{ and } F \propto 1/r^2$$

Combining the two relations,

$$F \propto \frac{m_1 m_2}{r^2}$$

or
$$\boxed{F = G\frac{m_1 m_2}{r^2}} \quad ...(3.12)$$

where G is a constant of proportionality which is known as *gravitational constant.* The value of G remains same at all places and it is independent of the nature of particles, temperature, medium, *etc*. Therefore, it is a *universal constant* and is known as universal gravitational constant.

It may be mentioned here that force is a vector quantity, hence it is necessary to indicate its direction also. The direction of force $\vec{F}_{12}$ on mass m_1 is towards m_2 along the line joining the masses m_1 and m_2, whereas the force $\vec{F}_{21}$ on mass m_2 is towards mass m_1 along the same line. Both these forces are equal in magnitude, but opposite in direction (*i.e.*, $\vec{F}_{12} = -\vec{F}_{21}$). Thus it is an action-reaction force *i.e.*, a particle exerts a force on other particle, equal and opposite to the force that the second particle exerts on the first particle.

Unit and value of universal gravitational constant

From eqn. (3.12), $G = \dfrac{F \times r^2}{m_1 \times m_2}$

$$\therefore \quad \text{S.I. unit of } G = \frac{\text{newton} \times \text{metre}^2}{\text{kilogram} \times \text{kilogram}}$$
$$= \text{N m}^2\,\text{kg}^{-2}$$

The value of G is $6{\cdot}67 \times 10^{-11}$ N m^2 kg^{-2}.

In eqn. (3.12), if m_1 = 1 kg, m_2 = 1 kg and r = 1 m, then $G = F$. Thus

Gravitational constant G is numerically equal to the magnitude of force of attraction between the two masses each of 1 kg *placed at a separation of* 1 m.

Examples : (1) The gravitational force of attraction between two bodies of masses m_1 = 1 kg and m_2 = 1 kg kept at a separation of r = 1 m is

$$F = \frac{(6{\cdot}67\times10^{-11})\times1\times1}{(1)^2} = 6{\cdot}67 \times 10^{-11} \text{ N.}$$

(2) The gravitational force of attraction between the moon (mass = $7{\cdot}36 \times 10^{22}$ kg) and the earth (mass = $5{\cdot}96 \times 10^{24}$ kg), taking the distance of moon from the earth to be $3{\cdot}80 \times 10^8$ m, is

$$F = \frac{(6{\cdot}67\times10^{-11})\times(5{\cdot}96\times10^{24})\times(7{\cdot}36\times10^{22})}{(3{\cdot}80\times10^8)^2}$$
$$= 2 \times 10^{20} \text{ N.}$$

From the above two examples, it is clear that the gravitational force of attraction is significant between the heavenly bodies, but it is insignificant between the ordinary bodies.

In fact, regarding the gravitational force, it is important to note that the gravitational force between the two masses :

(i) is always *attractive.*

(ii) is directly proportional to the *product of the masses.*

(iii) is inversely proportional to the square of separation between them, *i.e.* it obeys the inverse square law. Thus, by doubling the separation between the two masses, the force of attraction between them is reduced to one-fourth.

(iv) is significant between heavenly bodies, but is insignificant between ordinary bodies because of small magnitude of G.

Importance of the law of gravitation : Newton used this law to explain the motion of planets around the sun, the motion of the moon (satellite) around the earth and the motion of a freely falling body.

3.15 FORCE DUE TO GRAVITY

According to the law of gravitation, the earth attracts each object around it, towards its centre. The force with which the earth attracts a body is called the ***force due to gravity*** on the body, which can be taken to act vertically downwards at the centre of gravity of the body. In vertical motion *near* the earth surface for height much smaller than the radius of earth, the force of gravity on the body is assumed to be *same* throughout.

The force due to gravity on a body of mass m kept on the surface of earth of mass M and radius R, is equal to the force of attraction between the earth and that body. It is given as

$$F = \frac{GMm}{R^2} \qquad ....(3.13)$$

Taking the mass of earth $M = 5{\cdot}96 \times 10^{24}$ kg and the radius of earth $R = 6{\cdot}37 \times 10^6$ m, the force of gravity on a body of mass $m = 1$ kg on the surface of earth will be

$$F = \frac{(6{\cdot}67 \times 10^{-11}) \times (5{\cdot}96 \times 10^{24}) \times 1}{(6{\cdot}37 \times 10^6)^2} = 9{\cdot}8 \text{ N.}$$

Thus earth attracts a body of mass 1 kg by a force of 9·8 N towards its centre.

Note : As earth attracts an object towards it, the object also attracts the earth towards it by an equal force. Since the object is free to move, it starts moving towards the earth, but the earth because of its large inertia, does not move towards the object.

3.16 ACCELERATION DUE TO GRAVITY

Galileo was the first scientist to study the motion of different bodies under the force of attraction of earth (*i.e.*, gravity). From his experiments, Galileo found that if bodies of different masses and sizes (or shapes) are simultaneously made to fall in vacuum (*i.e.*, in absence of air)* from the same height, they all reach the earth surface simultaneously and with same velocity. Thus, all bodies travel the same distance in the same interval of time. Moreover, he found that the velocity of a freely falling body does not remain constant, but it increases at a constant rate, *i.e., the motion of a freely falling body is a uniformly accelerated motion*. This acceleration is same for all bodies. In other words, *the acceleration of a freely falling body does not depend on the mass of the body, its size and its shape, etc.* This acceleration is called the *acceleration due to gravity*. Thus

> *The rate at which the velocity of a freely falling body increases, is called the acceleration due to gravity.* In other words, *it is the acceleration produced in a freely falling body due to the gravitational force of attraction of the earth.*

The acceleration due to gravity is denoted by the letter g. Its S.I. unit is m s^{-2}. It is a **vector** quantity directed vertically downwards towards the centre of earth.

Experimentally, it is found that the value of acceleration due to gravity g does not remain constant. On the earth's surface, the value of g varies from place to place. On equator, it is slightly less as compared to that at poles. The mean value of g on the earth surface is 9·8 m s^{-2}. At altitudes above the earth's surface or at depth below the earth surface, the value of g decreases. The value of g is zero at the centre of earth.

Note : The value of g is different on different planets and satellites. The value of g on moon's surface is nearly one-sixth the value of g on earth's surface.

Relationship between g and G : Let g be the acceleration due to gravity at a planet (or satellite) of mass M and radius R. By Newton's law of motion, the force due to gravity on a body of mass m on its surface will be

$$F = \text{mass} \times \text{acceleration due to gravity}$$

or $$F = mg \qquad ....(3.14)$$

By Newton's gravitational law, this attractive force is given by $$F = \frac{GMm}{R^2} \qquad ...(3.15)$$

From eqns. (3.14) and (3.15),

$$\frac{GMm}{R^2} = mg$$

or $$\boxed{\text{acceleration due to gravity } g = \frac{GM}{R^2}} \qquad ...(3.16)$$

The above eqn. (3.16) relates the acceleration due to gravity g with the gravitational constant G. Obviously *the value of g on a planet (or satellite)*

* In presence of air, viscous force and force due to buoyancy act on the body upwards. These forces depend on size, shape and velocity of the body, so they are different in magnitude for different bodies. Therefore downward acceleration will not remain same (equal to g) for all bodies, so they will not reach simultaneously.

depends on the mass and radius of that planet (or satellite).

Examples : (1) Taking the mass of earth $M = 5{\cdot}96 \times 10^{24}$ kg and the radius of earth $R = 6{\cdot}37 \times 10^6$ m, the acceleration due to gravity at a place on the surface of earth comes out to be

$$g_{earth} = \frac{(6{\cdot}67\times10^{-11})\times(5{\cdot}96\times10^{24})}{(6{\cdot}37\times10^{6})^2} = 9{\cdot}8 \text{ m s}^{-2}.$$

(2) On the surface of moon (mass $M = 7{\cdot}36 \times 10^{22}$ kg and radius $R = 1{\cdot}75 \times 10^6$ m), the acceleration due to gravity at the surface of moon is

$$g_{moon} = \frac{(6{\cdot}67\times10^{-11})\times(7{\cdot}36\times10^{22})}{(1{\cdot}75\times10^{6})^2} = 1{\cdot}6 \text{ m s}^{-2}.$$

Obviously, $g_{moon} = \frac{1}{6}\, g_{earth}$ nearly.

3.17 FREE FALL

In chapter 2, we have studied one dimensional motion. The motion of a freely falling body from a height or the motion of a body thrown vertically upwards from the surface of earth, is the one dimensional motion under gravity. The acceleration of a vertically falling body is $a = +\,g$ and that of a body going vertically upwards is $a = -\,g$.

If a body *falls from rest* freely from a height h, under gravity then $u = 0$ and acceleration a is replaced by g (acceleration due to gravity), then equations of motion are :

$$\left.\begin{array}{lrcl} \text{(i)} & v & = & gt \\ \text{(ii)} & h & = & \frac{1}{2}gt^2 \\ \text{(iii)} & v^2 & = & 2gh \end{array}\right\} \qquad ...(3.17)$$

But if the initial velocity of fall of the body is u, then equations of motion are :

$$\left.\begin{array}{lrcl} \text{(i)} & v & = & u + gt \\ \text{(ii)} & h & = & ut + \frac{1}{2}gt^2 \\ \text{(iii)} & v^2 & = & u^2 + 2gh \end{array}\right\} \qquad ...(3.18)$$

If a body is thrown vertically up with an initial velocity u to a height h, there will be retardation ($a = -\,g$), then equations of motion are:

$$\left.\begin{array}{lrcl} \text{(i)} & v & = & u - gt \\ \text{(ii)} & h & = & ut - \frac{1}{2}gt^2 \\ \text{(iii)} & v^2 & = & u^2 - 2gh \end{array}\right\} \qquad ...(3.19)$$

At the highest point of reach, final velocity $v = 0$, thus maximum height reached $h_{max} = \frac{u^2}{2g}$ (from equation $v^2 = u^2 - 2gh$) and the time taken by the body to rise to the highest point $t = \frac{u}{g}$ (from equation $v = u - gt$). The same will be the time it takes to come back to the initial point after reaching the highest point. So the total time of journey $t' = 2t = \frac{2u}{g}$ and the total distance travelled by the body $h' = 2h_{max} = \frac{u^2}{g}$.

3.18 MASS AND WEIGHT

(a) Mass

The mass of a body is the quantity of matter it contains.

The mass is a **scalar** quantity. Its S.I. unit is kilogram (symbol kg). It is constant for a given body at rest and does not change by changing the place of the body. It is an intrinsic property of the body. It is measured by a physical balance (or beam balance) because the value of g (acceleration due to gravity) is same on both the pans. The mass of a body increases with its velocity*, but this change is perceptible only when the velocity of the body v becomes more than 10^6 m s^{-1} *i.e.*, reaches close to the speed of light c ($= 3 \times 10^8$ m s^{-1}), so for a body moving with velocity less than 10^6 m s^{-1}, its mass is taken to be constant.

(b) Weight

The weight of a body is the force with which the earth attracts it. In other words, weight of a body is the force of gravity on it.

The weight is a **vector** quantity. Its direction is downwards towards the centre of earth.

Unit of weight : The S.I. unit of weight is newton (N) and the C.G.S. unit is dyne where

$$1 \text{ N} = 10^5 \text{ dyne.}$$

Relationship between weight and mass : The weight of a body is related to its mass as follows :

Weight = mass × acceleration due to gravity

or $W = m \times g$ *i.e.*, $\boxed{W = mg}$ ... (3.20)

* $m = m_0/\sqrt{1-(v/c)^2}$ where m_0 is the mass of the body at rest.

Note : From eqn. (3.20), the S.I. unit of acceleration due to gravity g can also be written as newton per kilogram (or N kg^{-1}) in place of metre/second^2 (or m s^{-2}).

Since the value of g varies from place to place, the weight of a given body also varies from place to place.

The gravitational unit of weight in M.K.S. system is kilogram force (kgf) and in C.G.S. system is gram force (gf), where

$$1 \text{ kgf} = 9{\cdot}8 \text{ N}$$

and $$1 \text{ gf} = 980 \text{ dyne}$$

Obviously a body of mass m kg will weigh m kgf.

The weight of a body can be measured by a spring balance directly in newton and also by a physical balance in kgf.

Comparison of mass and weight

Mass	Weight
1. It is a measure of the quantity of matter contained in the body, at rest.	1. It is the force with which the earth attracts the body.
2. It is a scalar quantity.	2. It is a vector quantity
3. Its S.I. unit is kg.	3. Its S.I. unit is newton (N).
4. It is measured by a physical (or beam) balance.	4. It is measured by a spring balance which is calibrated to read in newton.
5. It is constant for a body and does not change with the change in place.	5. It is not constant for a body, but varies from place to place due to change in the value of g.

3.19 GRAVITATIONAL UNITS OF FORCE

In M.K.S. system, the gravitational unit of force is *kilogram force* (kgf).

One kilogram force is the force due to gravity on a mass of 1 kg.

i.e., 1 kgf = force due to gravity on a mass of 1 kg
= mass 1 kg × acceleration due to gravity g m s^{-2}
= g newton

Since average value of g is 9·8 m s^{-2},

∴ 1 kgf = 9·8 newton (or 9·8 N)

In C.G.S. system, the gravitational unit of force is *gram force* (gf).

One gram force is the force due to gravity on a mass of 1 g.

i.e., 1 gf = force due to gravity on a mass of 1 g
= mass 1g × acceleration due to gravity g cm s^{-2}
= g dyne

Since average value of g is 980 cm s^{-2},

∴ $\boxed{1 \text{ gf} = 980 \text{ dyne}}$

Further, 1 kgf = 1000 gf

To an approximation 1 kgf is assumed to be nearly equal to 10 N. Then 1 N = 0·1 kgf or 100 gf. Thus one can feel a force of 1 N by holding a mass of 100 g on his palm as shown in Fig. 3.19.

Obviously, if we say that 1 kgf = 9·8 N, we mean that we have to exert a force of 9·8 N to hold a mass of 1 kg on our palm.

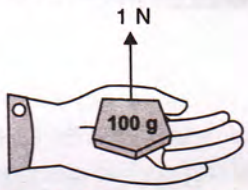

Fig. 3.19 Force of 1 N exerted by palm on a mass of 100 gramme to hold it

EXAMPLES

1. Calculate the gravitational force of attraction between the two bodies of masses 40 kg and 80 kg separated by a distance 15 m. Take $G = 6{\cdot}7 \times 10^{-11}$ N m^2 kg^{-2}.

Given, $m_1 = 40$ kg, $m_2 = 80$ kg, $G = 6{\cdot}7 \times 10^{-11}$ N m^2 kg^{-2}, $r = 15$ m

Gravitational force of attraction

$$F = \frac{G m_1 m_2}{r^2} = \frac{(6{\cdot}7\times10^{-11})\times40\times80}{(15)^2} = \mathbf{9{\cdot}5 \times 10^{-10}\ N}$$

2. Taking the mass of earth equal to 6×10^{24} kg and its radius equal to $6{\cdot}4 \times 10^6$ m, calculate the value of acceleration due to gravity at a height of 2000 km above the earth surface. Take $G = 6{\cdot}7 \times 10^{-11}$ N m^2 kg^{-2}.

When the body is at a height h = 2000 km = 2000 × 10^3 m = 2 × 10^6 m above the earth surface, the distance of body from centre of earth will be $r = R + h$ = $(6{\cdot}4 \times 10^6) + (2 \times 10^6) = 8{\cdot}4 \times 10^6$ m. Then

$$g = \frac{GM}{r^2} = \frac{GM}{(R+h)^2}$$

or $g = \frac{(6.7\times10^{-11})\times(6\times10^{24})}{(8.4\times10^{6})^2}$ = **5·7 m s⁻².**

3. A body of mass 10 kg is taken from the earth to the moon. If the value of g on earth is 9·8 m s^{-2} and on moon is 1·6 m s^{-2}, find : (i) the weight of the body on earth, (ii) the mass and weight of the body on moon.

Given, mass on earth m = 10 kg,

g_{earth} = 9·8 m s^{-2}; g_{moon} = 1·6 m s^{-2}.

(i) Weight of the body on earth = mass × g_{earth}

= 10 × 9·8 = **98 N**

(ii) Mass of the body on moon

= Mass of the body on earth = **10 kg**

Weight of the body on moon = $m \times g_{moon}$

= 10 × 1·6 = **16 N**

4. A stone is dropped from rest and falls freely under gravity. Calculate the distance covered by it in the first two seconds. (g = 9·8 m s^{-2})

Given, $u = 0$, $a = g$ = 9·8 m s^{-2} and t = 2 s.

From equation of motion $h = ut + \frac{1}{2}gt^2$

∴ Distance covered $h = 0 \times 2 + \frac{1}{2} \times 9.8 \times (2)^2$

= 0 + 19·6 = **19·6 m.**

5. A stone is dropped freely in a river from a bridge. It takes 5 s to touch the water surface in the river. Calculate : (i) the height of the bridge from the water level, (ii) the distance covered by the stone in 2 s (g = 9·8 m s^{-2}).

Given, $u = 0$, $a = g$ = 9·8 m s^{-2}, t = 5 s

(i) From equation of motion $h = ut + \frac{1}{2}gt^2$

$h = 0\times5 + \frac{1}{2}\times9.8\times(5)^2$

$= 9.8 \times \frac{25}{2} = 122.5$ m

∴ Height of the bridge = **122·5 m**

(ii) Distance covered by the stone in t = 2 s

$S = ut + \frac{1}{2}gt^2 = 0 + \frac{1}{2} \times 9.8 \times (2)^2$ = **19·6 m.**

6. A body is dropped freely under gravity from the top of a tower of height 78·4 m. Calculate :

(i) the time to reach the ground, and

(ii) the velocity with which it strikes the ground.

Take g = 9·8 m s^{-2}.

Given, $u = 0$, h = 78·4 m, $a = g$ = 9·8 m s^{-2}.

(i) From equation of motion $h = ut + \frac{1}{2}gt^2$

$78.4 = 0 \times t + \frac{1}{2} \times 9.8 \times t^2$

or $78.4 = 4.9\,t^2$

or $t^2 = \frac{78.4}{4.9} = 16$

∴ Time to reach the ground $t = \sqrt{16}$ = **4 s**

(ii) From equation of motion $v = u + gt$

$v = 0 + 9.8 \times 4 = 39.2$ m s^{-1}.

i.e., the body strikes the ground with velocity **39·2 m s⁻¹**.

7. A ball is thrown vertically upwards. It goes to a height 19·6 m and then comes back to the ground. Find :

(i) the initial velocity of the ball,

(ii) the total time of journey, and

(iii) the final velocity of the ball when it strikes the ground.

Take g = 9·8 m s^{-2}.

Given, h = 19·6 m, $a = -g = -9.8$ m s^{-2}, $v = 0$

(i) From equation of motion $v^2 = u^2 + 2gh$

$0 = u^2 - 2 \times 9.8 \times 19.6$

or $u^2 = 19.6 \times 19.6$

∴ Initial velocity u = **19·6 m s⁻¹**.

(ii) Let t s be the time taken by the ball to reach the highest point.

From equation of motion $v = u + gt$

$0 = 19.6 - 9.8\,t$ or $9.8\,t = 19.6$

∴ $t = \frac{19.6}{9.8} = 2$ s

It will take the same time t = 2 s to come back from the highest point to the ground.

∴ Total time of journey $t' = 2t = 2 \times 2$ = **4 s.**

(iii) The final velocity of ball when it strikes the ground will be same as the initial velocity with which it was thrown upwards.

∴ Final velocity on reaching the ground = **19·6 m s⁻¹**.

8. A ball is thrown vertically upwards from the top of a building of height 24·5 m with an initial velocity 19·6 m s^{-1}. Taking g = 9·8 m s^{-2}, calculate : (i) the height to which it will rise before returning to the ground, (ii) the velocity with which it will strike the ground, and (iii) the total time of journey.

Given, u = 19·6 m s^{-1} (upwards), height of building x = 24·5 m.

(i) At the highest point, $v = 0$.

For upward journey, from relation $v^2 = u^2 - 2gh$

$0 = u^2 - 2gh$

or $$h = \frac{u^2}{2g} = \frac{(19 \cdot 6)^2}{2 \times 9 \cdot 8} = \mathbf{19 \cdot 6\ m}$$

(ii) While returning from the highest point, $u = 0$, total height travelled = 19·6 + 24·5 = 44·1 m. Let v be the velocity with which it strikes the ground. Then from relation $v^2 = u^2 + 2\,gh$,

$$v^2 = 0 + 2 \times 9 \cdot 8 \times 44 \cdot 1.$$

$$\therefore \quad v = \sqrt{2 \times 9 \cdot 8 \times 44 \cdot 1} = \mathbf{29 \cdot 4\ m\ s^{-1}}$$

(iii) If the ball takes time t_1 to go to the highest point from the top of building, then for upward journey, from relation $v = u - gt$,

$$0 = 19 \cdot 6 - 9 \cdot 8\, t_1 \quad \text{or} \quad t_1 = \frac{19 \cdot 6}{9 \cdot 8} = 2\ \text{s}$$

Now for downward journey from the highest point, if the ball takes time t_2 to reach the ground, then $u = 0$, $v = 29{\cdot}4$ m s^{-1}.

From relation $v = u + gt$.

$$29 \cdot 4 = 0 + 9 \cdot 8\, t_2$$

$$\therefore \quad t_2 = \frac{29 \cdot 4}{9 \cdot 8} = 3\ \text{s}$$

Hence total time of journey $t = t_1 + t_2$

$= 2 + 3 = \mathbf{5\ s.}$

EXERCISE 3(E)

1. State Newton's law of gravitation.
2. State whether the gravitational force between *two* masses is attractive or repulsive ?
Ans. Always attractive
3. Write an expression for the gravitational force of attraction between *two* bodies of masses m_1 and m_2 separated by a distance r.
4. How does the gravitational force of attraction between two masses depend on the distance between them ?
5. How is the gravitational force between two masses affected if the separation between them is doubled ? **Ans.** Force reduces to one-fourth
6. Define gravitational constant G.
7. Write the numerical value of gravitational constant G with its S.I. unit.
8. What is the importance of the law of gravitation ?
9. What do you understand by the term force due to gravity ?
10. Write an expression for the force due to gravity on a body of mass m and explain the meaning of the symbols used in it.
11. Define the term acceleration due to gravity ? Write its S.I. unit.
12. Write down the average value of g on the earth's surface.
13. How is the acceleration due to gravity on the surface of earth related to its mass and radius ?
14. How are g and G related ?
15. A body falls freely under gravity from rest and reaches the ground in time t. Write an expression for the height fallen by the body. **Ans.** $h = \frac{1}{2} gt^2$
16. A body is thrown vertically upwards with an initial velocity u. Write expression for the maximum height attained by the body.
Ans. $h = u^2/2g$
17. Define the terms mass and weight.
18. Distinguish between mass and weight.
19. State the S.I. units of (a) mass and (b) weight.
20. The value of g at the centre of earth is zero. What will be the weight of a body of mass m kg at the centre of earth ? **Ans.** Zero
21. Which of the following quantity does not change by change of place of a body : mass or weight ? **Ans.** Mass
22. Explain the meaning of the following statement '1 kgf = 9·8 N'.

Multiple choice type :

1. The gravitational force between the two bodies is :
   (a) always repulsive
   (b) always attractive
   (c) attractive only at large distances
   (d) repulsive only at large distances.
   Ans. (b) always attractive
2. The value of G is :
   (a) 9·8 N m^2 kg^{-2}
   (b) $6 \cdot 7 \times 10^{-11}$ N m^2 kg^{-2}
   (c) $6 \cdot 7 \times 10^{-11}$ m s^{-2}
   (d) 6·7 N kg^{-1}
   Ans. (b) $6 \cdot 7 \times 10^{-11}$ N m^2 kg^{-2}
3. The force of attraction between the two masses each of 1 kg kept at a separation of 1 m is :
   (a) 9·8 N (b) 6·7 N
   (c) 980 N (d) $6 \cdot 7 \times 10^{-11}$ N
   Ans. (d) $6 \cdot 7 \times 10^{-11}$ N
4. A body is projected vertically upward with an initial velocity u. If acceleration due to gravity is g, the time for which it remains in air, is :
   (a) $\frac{u}{g}$ (b) ug
   (c) $\frac{2u}{g}$ (d) $\frac{u}{2g}$ **Ans.** (c) $\frac{2u}{g}$

5. An object falling freely from rest reaches ground in 2 s. If acceleration due to gravity is $9{\cdot}8$ m s^{-2}, the velocity of the object on reaching the ground will be :
(a) $9{\cdot}8$ m s^{-1} (b) $4{\cdot}9$ m s^{-1}
(c) $19{\cdot}6$ m s^{-1} (d) zero.
Ans. (c) $19{\cdot}6$ m s^{-1}

Numericals :

1. The force of attraction between the two bodies at a certain separation is 10 N. What will be the force of attraction between them if the separation is reduced to half ? **Ans.** 40 N
2. Write the approximate weight of a body of mass 5 kg. What assumption have you made ?
Ans. 50 N (Assumption : g = 10 m s^{-2}).
3. Calculate the weight of a body of mass 10 kg in (a) kgf and (b) newton. Take g = $9{\cdot}8$ m s^{-2}.
Ans. (a) 10 kgf (b) 98 newton.
4. State the magnitude and direction of the force of gravity acting on a body of mass 5 kg. Take g = $9{\cdot}8$ m s^{-2}.
Ans. Force of gravity on the body = 49 newton vertically downwards.
5. The weight of a body is $2{\cdot}0$ N. What is the mass of the body ? (g = 10 m s^{-2}) **Ans.** $0{\cdot}2$ kg
6. The weight of a body on earth is 98 N where the acceleration due to gravity is $9{\cdot}8$ m s^{-2}. What will be its (a) mass and (b) weight on moon where the acceleration due to gravity is $1{\cdot}6$ m s^{-2} ? **Ans.** (a) 10 kg (b) 16 N
7. A man weighs 600 N on earth. What would be his approximate weight on moon ? Give reason for your answer ? **Ans.** 100 N
Reason : The value of g on moon = $\frac{1}{6}$ th the value of g on earth.
8. What is the (a) force of gravity and (b) weight of a block of mass $10{\cdot}5$ kg ? Take g = 10 m s^{-2}. **Ans.** (a) 105 N, (b) 105 N
9. A ball is released from a height and it reaches the ground in 3 s. If g = $9{\cdot}8$ m s^{-2}, find :
(a) the height from which the ball was released,
(b) the velocity with which the ball will strike the ground.
Ans. (a) $44{\cdot}1$ m (b) $29{\cdot}4$ m s^{-1}
10. What force, in newton, your muscles need to apply to hold a mass of 5 kg in your hand ? State the assumption.
Ans. 49 N. **Assumption :** g = $9{\cdot}8$ N kg^{-1}.
11. A ball is thrown vertically upwards. It goes to a height 20 m and then returns to the ground. Taking acceleration due to gravity g to be 10 m s^{-2}, find :
(a) the inital velocity of the ball
(b) the final velocity of the ball on reaching the ground and
(c) the total time of journey of the ball.
Ans. (a) 20 m s^{-1} (b) 20 m s^{-1} (c) 4 s
12. A body is dropped from the top of a tower. It acquires a velocity 20 m s^{-1} on reaching the ground. Calculate the height of the tower. (Take g = 10 m s^{-2}) **Ans.** 20 m.
13. A ball is thrown vertically upwards. It returns 6 s later. Calculate : (i) the greatest height reached by the ball, and (ii) the initial velocity of the ball. (Take g = 10 m s^{-2})
Ans. (i) 45 m, (ii) 30 m s^{-1}
14. A pebble is thrown vertically upwards with a speed of 20 m s^{-1}. How high will it be after 2 s ? (Take g = 10 m s^{-2}) **Ans.** 20 m
15. (a) How long will a stone take to fall to the ground from the top of a building 80 m high and (b) what will be the velocity of the stone on reaching the ground ? (Take g = 10 m s^{-2})
Ans. (a) 4 s, (b) 40 m s^{-1}
16. A body falls from the top of a building and reaches the ground $2{\cdot}5$ s later. How high is the building ? (Take g = $9{\cdot}8$ m s^{-2}) **Ans.** $30{\cdot}6$ m
17. A ball is thrown vertically upwards with an initial velocity of 49 m s^{-1}. Calculate : (i) the maximum height attained, (ii) the time taken by it before it reaches the ground again. (Take g = $9{\cdot}8$ m s^{-2}). **Ans.** (i) $122{\cdot}5$ m, (ii)10 s
18. A stone is dropped freely from the top of a tower and it reaches the ground in 4 s. Taking g = 10 m s^{-2}, calculate the height of the tower.
Ans. 80 m
19. A pebble is dropped freely in a well from its top. It takes 20 s for the pebble to reach the water surface in the well. Taking g = 10 m s^{-2} and speed of sound = 330 m s^{-1}, find : (i) the depth of water surface, and (ii) the time when echo is heard after the pebble is dropped.
Ans. (i) 2000 m (ii) $26{\cdot}1$ s
20. A ball is thrown vertically upwards from the top of a tower with an initial velocity of $19{\cdot}6$ m s^{-1}. The ball reaches the ground after 5 s. Calculate : (i) the height of the tower, (ii) the velocity of ball on reaching the ground. Take g = $9{\cdot}8$ m s^{-2}.
Ans. (i) $24{\cdot}5$ m (ii) $29{\cdot}4$ m s^{-1}.

4 PRESSURE IN FLUIDS AND ATMOSPHERIC PRESSURE

Syllabus :
Change of pressure with depth (including the formula $P = h\rho g$); Transmission of pressure in liquids; Atmospheric pressure.
Scope : Thrust and pressure and their units; pressure exerted by a liquid column $P = h\rho g$; simple daily life examples : (i) broadness of the base of a dam, (ii) Diver's suit *etc.*, some consequences of $P = h\rho g$; transmission of pressure in liquids; Pascal's law; examples; Atmospheric pressure; common manifestation and consequences. Variation of pressure with altitude, (qualitative only); applications such as weather forecasting and altimeter. (Simple numerical problems).

(A) PRESSURE IN FLUIDS AND ITS TRANSMISSION

4.1 THRUST AND PRESSURE

Thrust : A force can be applied on a surface in any direction. If a force is applied in a direction normal (or perpendicular) to the surface, it is called the *thrust*. Thus,

Thrust is the force acting normally on a surface.

The thrust exerted by a body placed on a surface is equal to its weight. The thrust is *same* in whatsoever position the body is placed on the surface. Thus,

Thrust exerted by a body on a surface
= Weight of the body ....(4.1)

Thrust is a ***vector*** quantity.

Unit of thrust : It is measured in the units of force. The S.I. unit of thrust is newton (N) and C.G.S. unit of thrust is dyne, where $1 \text{ N} = 10^5$ dyne.

The gravitational unit of thrust in M.K.S. system is kgf and in C.G.S. system is gf. They are related as :

1 kgf = 9·8 N and 1 gf = 980 dyne

Pressure : The effect of thrust depends on the area of the surface on which it acts. *The effect of a thrust is less on a large area*, while *it is more on a small area.*

Example : If you stand on loose sand, your feet sink into the sand, but if you lie on that sand, your body does not sink into the sand. In both the cases, the thrust exerted on the sand is same (equal to your weight). But when you lie on sand, the thrust acts on a larger area and when you stand, the same thrust acts on a smaller area.

The effect of thrust is expressed in terms of thrust per unit area. This quantity is called *pressure*. Thus

Pressure is the thrust per unit area of surface.

If a thrust F acts on an area A, then

$$\textit{Pressure} = \frac{\textit{Thrust}}{\textit{Area}} \quad \text{or} \quad P = \frac{F}{A} \qquad ..(4.2)$$

Pressure is a ***scalar*** quantity.

Units of pressure

From relation (4.2), pressure = $\frac{\text{thrust}}{\text{area}}$

$\therefore$ Unit of pressure = $\frac{\text{Unit of thrust}}{\text{Unit of area}}$

S.I. unit : The S.I. unit of thrust is newton and that of area is metre^2, so the S.I. unit of pressure is newton per metre^2 which is abbreviated as N m^{-2}. This unit is named *pascal* (symbol Pa) after the name of the french scientist Blaise Pascal. *i.e.*,

$$1 \text{ pascal (or 1 Pa)} = \frac{1 \text{ Newton}}{1 \text{ metre}^2}$$

or $\quad 1 \text{ Pa} = 1 \text{ N m}^{-2}$

Thus

One pascal is the pressure exerted on a surface of area* 1 m^2 *by a force of* 1 N *acting normally on it.

However, if thrust is measured in kgf and area in m^2, the unit of pressure is kgf m^{-2}.

C.G.S. unit : The C.G.S. unit of pressure is dyne cm^{-2} where

1 dyne cm^{-2} = 0·1 N m^{-2} or 1 N m^{-2} = 10 dyne cm^{-2}.

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If thrust is measured in gf and area in cm^2, the unit of pressure is gf cm^{-2}.

Other units : Other units of pressure are *bar* and *millibar,* where

1 bar = 10^5 N m^{-2} and 1 millibar = 10^{-3} bar = 10^2 N m^{-2}.

The atmospheric pressure is generally expressed in terms of the height of mercury column in the barometre. At normal temperature and pressure, the barometric height is 0·76 m of Hg (or 76 cm of Hg or 760 mm of Hg) at sea level which is taken as one atmosphere. Thus atmospheric pressure is also expressed in a unit *atmosphere* (symbol atm) where

1 atmosphere (atm) = 0·76 m of Hg = 1·013 × 10^5 Pa

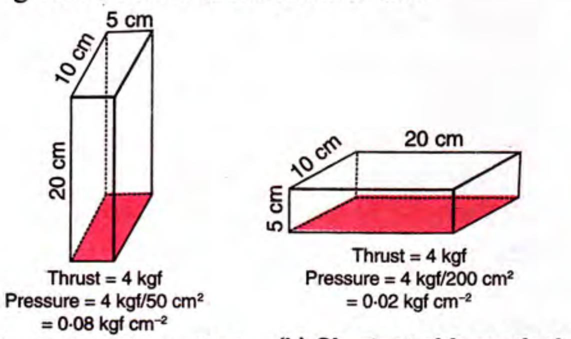
Sometimes we use *torr* as unit of atmospheric pressure after the name of the scientist Torricelli where

1 torr = 1 mm of Hg

and 1 atm = 760 torr.

Factors affecting the pressure : The pressure exerted on a surface depends on *two* factors : (i) the area on which the thrust is applied, and (ii) the thrust.

Examples : **(1)** A brick of weight 4 kgf having dimensions 20 cm × 10 cm × 5 cm exerts maximum pressure on ground when it is placed with its longest side (20 cm) vertical [Fig 4.1(a)], while it exerts minimum pressure on ground when it is placed with its shortest side (5 cm) vertical [Fig. 4.1(b)], even though the thrust is same in each case.



(a) Longest side vertical **(b) Shortest side vertical**

Fig. 4.1 Thrust and pressure

In Fig. 4.1(a), Thrust = 4 kgf

Area of base = 5 cm × 10 cm = 50 cm^2

$$\therefore \text{ Pressure on base (or ground)} = \frac{4\text{ kgf}}{50\text{ cm}^2} = 0{\cdot}08\text{ kgf cm}^{-2}$$

In Fig. 4.1(b), Thrust = 4 kgf

Area of base = 10 cm × 20 cm = 200 cm^2

$$\therefore \text{ Pressure on base (or ground)} = \frac{4\text{ kgf}}{200\text{ cm}^2} = 0{\cdot}02\text{ kgf cm}^{-2}$$

Thus pressure on ground in Fig. 4.1(b) is one-fourth of pressure in Fig. 4.1(a).

Obviously, *larger the area on which a given thrust acts, lesser is the pressure exerted by it.*

(2) In Fig. 4.1(b), if another identical brick is placed over the first brick, the thrust gets doubled (= 8 kgf) and since it acts on same area of base (= 200 cm^2), so the pressure on ground becomes = 8 kgf / 200 cm^2 = 0·04 kgf cm^{-2} (*i.e.*, it gets doubled).

Thus *larger the thrust acting on a given area, greater is the pressure exerted on it.*

Way of increasing pressure : *For the given thrust, the pressure on a surface is increased by reducing the area of surface.*

Examples : (a) The ends of nails (or pins) are made pointed so that large pressure is exerted at the pointed ends and they can be driven into, with a less effort.

(b) The cutting tools also have either sharp (or pointed) edges so that even a small thrust may cause a great pressure at the edges and cutting can be done with a less effort.

Way of decreasing pressure : *For the given thrust, the pressure on a surface is reduced by increasing the area of surface.*

Examples : (a) Wide wooden sleepers are placed below the railway tracks so that the pressure exerted by the iron rails on the ground becomes less.

(b) The foundations of buildings are made wider than the walls so that the pressure exerted by the building on the ground becomes less.

4.2 PRESSURE IN FLUIDS

A substance which can flow is called a *fluid.* All liquids and gases are, thus, fluids.

A solid exerts pressure on a surface due to its weight. Similarly, a fluid also exerts pressure due to its weight. A solid exerts pressure only on the surface on which it is placed *i.e.*, at its bottom, but a fluid exerts pressure on the bottom as well as on the walls of the container due to its tendency to flow. A fluid, therefore, exerts pressure in all directions. Thus,

> *A fluid contained in a vessel exerts pressure at all points and in all directions.*

Experimental demonstration : Take a vessel filled with a liquid (say, water). Place it on a horizontal surface. Make several small holes in the wall of the vessel anywhere below the free surface of liquid. It is observed that :

(1) The liquid spurts out through each hole. This shows that the liquid exerts pressure at each point on the wall of the vessel.

(2) If we put our finger on any of the hole, finger feels a thrust due to liquid. This demonstrates that the liquid contained in the vessel exerts thrust at all points below its free surface. Thrust on unit area at a point gives the pressure due to liquid at that point.

(3) If we note the distance from the bottom of the vessel to the point where the liquid from a hole strikes on the horizontal surface, it is noticed that as the depth of the hole below the free surface of liquid increases, the throw of liquid also increases *i.e.*, the liquid reaches to a greater distance on the horizontal surface. This shows that liquid pressure at a point increases with the increase of depth of point from its free surface (Fig. 4.2).

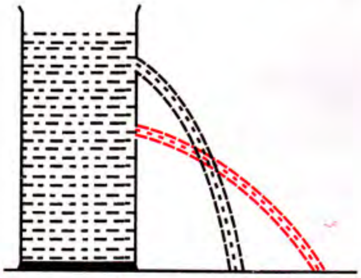


Fig. 4.2 Liquid pressure increases with increase of depth below the free surface

4.3 PRESSURE EXERTED BY A LIQUID COLUMN ($P = h\rho g$)

The pressure exerted by a liquid of density ρ at a depth h is $P = h\rho g$ where g is the accelration due to gravity *i.e.*,

> Pressure $P = h\,\rho\,g$
> = ***depth × density of liquid × acceleration due to gravity*** ....(4.3)

Proof : Consider a vessel containing a liquid of density ρ. Let the liquid be stationary. In order to calculate pressure at a depth h, consider a horizontal circular surface PQ of area A at depth h below the free surface XY of the liquid (Fig. 4.3). The pressure on surface PQ will be due to the weight of the liquid coloumn above the surface PQ (*i.e.*, the liquid contained in cylinder $PQRS$ of height h with PQ as its base and top face RS lying on the free surface XY of the liquid).

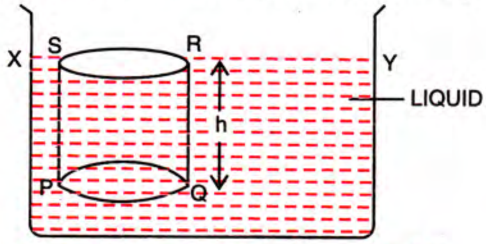


Fig. 4.3 Pressure at a depth in a liquid

The thrust exerted on the surface PQ

= Weight of the liquid column $PQRS$

= Volume of liquid column $PQRS$ × density × g

= (Area of base PQ × height) × density × g

$= (A \times h) \times \rho \times g = A\,h\,\rho\,g$ ....(4.4)

This thrust is exerted on the surface PQ of area A. Therefore, pressure

$$P = \frac{\text{Thrust on surface}}{\text{Area of surface}} = \frac{A h \rho g}{A} = h\rho g$$

Note : Since there is atmospheric pressure above the free surface of liquid, so to find the total pressure at a depth inside a liquid, it must also be taken into consideration. If the atmospheric pressure acting on the free surface of liquid is P_0, then.

> *Total pressure in a liquid at a depth h*
> = *Atmospheric pressure + pressure due to liquid column*
> = $P_0 + h\rho g$ ......(4.5)

Factors affecting the pressure at a point in a liquid

From eqn. (4.4), it is clear that the pressure at a point inside the liquid depends directly on the following *three* factors :

(i) depth of the point below the free surface (h),

(ii) density of liquid (ρ), and

(iii) acceleration due to gravity (g).

At a particular place on the earth surface, the acceleration due to gravity g is constant, therefore, the pressure at a point in a liquid is (i) directly proportional to the depth h of the point below the free surface of the liquid, and (ii) directly proportional to the density ρ of the liquid.

However, the pressure inside a liquid does not depend on (i) the shape and size of the vessel in which the liquid is contained, and (ii) the area of surface on which it acts.

4.4 LAWS OF LIQUID PRESSURE

Following are the *five* laws of liquid pressure :

(i) Inside the liquid, pressure *increases with the increase in depth* from its free surface.

(ii) In a stationary liquid, pressure is *same at all points on a horizontal plane.*

(iii) Pressure is *same in all directions about a point* in liquid.

(iv) Pressure at same depth is *different in different liquids*. It increases with the increase in density of liquid.

(v) A liquid seeks its own level.

4.5 SOME CONSEQUENCES OF LIQUID PRESSURE $P = h\rho g$

(i) In sea water, the pressure at a certain depth in sea water is more than that at the same depth in river water : The reason is that the density of sea water is more than the density of river water.

(ii) The wall of a dam is made thicker at the bottom : Fig. 4.4 shows the side view of a dam. The thickness of its wall increases from top towards the bottom. The reason is that the pressure exerted by a liquid increases with its depth. Thus as depth increases, more and more pressure is exerted by water on the wall of dam. A thicker wall is required to withstand a greater pressure, therefore, the wall of the dam is made with thickness increasing towards the base. In Fig. 4.4, the increasing length of arrows in water shows the increasing pressure on the wall of dam towards the bottom.

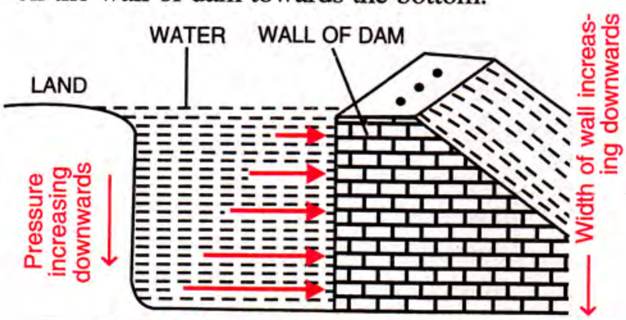


Fig. 4.4 Wall of a dam with its thickness increasing towards the bottom

(iii) Water supply tank is placed high : To supply water in a town (or colony), the tank to store water for supply is made at a sufficient height. The reason is that as greater is the height of tank, more will be the pressure of water in the taps of a house. Thus for a good supply of water, the height of the supply tank must always be a few metre higher than the level at which supply of water is to be made.

(iv) Diver's suit : The sea divers need special protective suit to wear because in deep sea, the total pressure exerted on the diver's body is much more than his blood pressure. To withstand it, he needs to wear a special protective suit, made from glass reinforced plastic or cast aluminium. The pressure inside the suit is maintained at one atmosphere.

(v) Size of gas bubble inside the water : It is noticed that as *the gas bubble formed at the bottom of a lake, rises, it grows in size*. The reason is that when the bubble is at the bottom of lake, total pressure exerted on it is the sum of the atmospheric pressure and the pressure due to water column. As the gas bubble rises, due to decrease in depth, the pressure due to water column decreases, so the total pressure exerted on the bubble decreases. According to Boyle's law, the volume of bubble increases due to the decrease in pressure, *i.e.*, the bubble grows in size. When the bubble reaches the surface of liquid, total pressure exerted on it becomes just equal to the atmospheric pressure only which is minimum and so the size of bubble on surface becomes maximum.

4.6 TRANSMISSION OF PRESSURE IN LIQUIDS; PASCAL'S LAW

We have read that the pressure due to liquid at a point in a liquid of density ρ at a depth h below its free surface is $P = h\rho g$. Obviously, the pressure difference between any two points x and y in a stationary liquid will depend only on the difference in vertical height (Δh) between these points. Now if by some means, the pressure at one point x is increased, the pressure at other point y must also increase by the same amount so that the difference in pressure between the two points x and y may remain same. Thus pressure exerted at a point x is equally transmitted to the point y. This is *Pascal's law*. Thus,

Pascal's law states that the pressure exerted anywhere in a confined liquid is transmitted equally and undiminished in all directions throughout the liquid.

This can be demonstrated by the following experiment.

Experiment : Take a glass flask having narrow tubes coming out from its sides and bottom. The flask is provided with an air-tight piston at its mouth as shown in Fig. 4.5. Fill the flask with water. *The water in each tube will be at the same level.* The initial level of water in each tube is shown by the dotted black line. Now push the piston down into the flask gently. It is observed that jets of water rises out from each tube, reaching the same height which is shown by the upper dotted coloured line. This shows that the pressure applied to the enclosed liquid is transmitted equally in all directions every where inside the liquid.

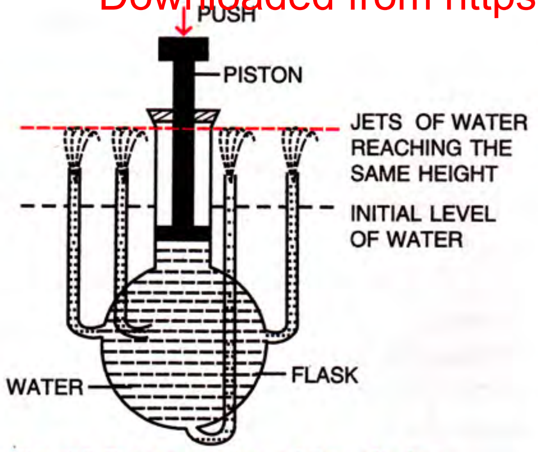


Fig. 4.5 Demonstration of Pascal's law

4.7 APPLICATION OF PASCAL'S LAW

Hydraulic machines such as *hydraulic press, hydraulic jack* and *hydraulic brakes* are based on Pascal's law of transmission of pressure in liquids.

Principle of a hydraulic machine

The principle of each hydraulic machine is that *a small force applied on a smaller piston is transmitted to produce a large force on the bigger piston.*

Fig. 4.6 shows two cylindrical vessels P and Q connected by a horizontal tube R. The vessels contain a liquid (or water) and they are provided with water-tight pistons A and B. The vessel P is of smaller diameter as compared to the vessel Q. Let area of cross section of the vessel P be A_1 and that of the vessel Q be A_2. When a weight is placed on the piston A, it exerts a force F_1 on the piston A. Therefore the pressure applied on the piston A is

$$P_1 = \frac{F_1}{A_1} \qquad \text{....(4.6)}$$

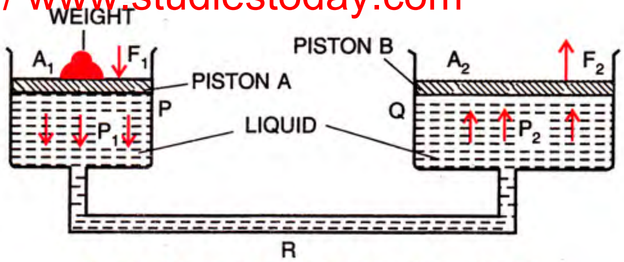


Fig. 4.6 Principle of a hydraulic machine

According to Pascal's law, the pressure exerted on piston A is transmitted through the liquid to the piston B. This exerts an upward pressure P_2 on the piston B which is equal to P_1. Thus

$$P_2 = P_1 \qquad \text{....(4.7)}$$

If the upward force exerted on piston B is F_2, Then

$$\text{Pressure on piston } B \text{ is } P_2 = \frac{F_2}{A_2} \qquad \text{....(4.8)}$$

From eqns. (4.6), (4.7) and (4.8), $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

or

$$\boxed{\frac{F_2}{F_1} = \frac{A_2}{A_1}} \qquad \text{.....(4.9)}$$

Since $A_2 > A_1$, therefore $F_2 > F_1$

Thus a small force F_1 applied on the smaller piston A can be used to produce a large force F_2 on the bigger piston B. This is the principle of a hydraulic machine which acts as a *force multiplier*.

4.8 EXAMPLES OF HYDRAULIC MACHINES

(i) Hydraulic press (or Bramah press)

A hydraulic press works on the principle of Pascal's law.

Construction : Fig. 4.7 shows a hydraulic press. It consists of two hollow cylinders P and Q

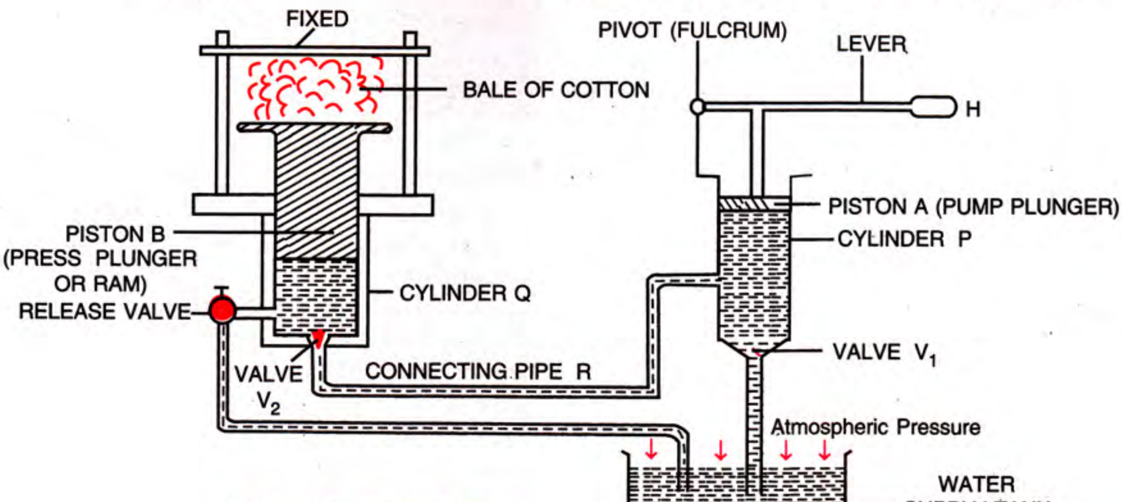


Fig. 4.7 Hydraulic press

fitted with valves V_1 and V_2 respectively, at their bottom. The cylinder P has a tank (or reservoir) at the bottom connected through the valve V_1. The area of cross section of cylinder Q is larger than that of P. Water-tight pistons A and B are fitted in these cylinders. Let the area of cross sections of pistons A and B be A_1 and A_2 respectively. The two cylinders are connected by a pipe R. The piston A of the smaller cylinder is called the *pump plunger* and piston B of the larger cylinder is called the *ram* (or *press plunger*). To press down or raise up the pump plunger A, a lever arrangement provided with a handle H is used. The cylinder Q at its bottom is provided with a *release valve* which joins it to the reservoir.

Principle : When a force F_1 is applied on the piston A, it exerts a pressure on liquid contained in the cylinder P. According to Pascal's law, this pressure is transmitted through liquid in tube R to the piston B of the other cylinder Q due to which the piston B tends to move upwards. Since the area of cross section of cylinder P is less than that of the cylinder Q, therefore by applying a small force on the piston A, we can lift a large weight kept on the piston B.

When no weight is placed on the piston B, it rises up against a fixed roof with a force F_2 ($F_2 > F_1$). If a bale of cotton is kept on the press plunger B, it gets compressed.

Working : When the pump plunger A is raised by raising the handle H, the pressure in cylinder P decreases and the valve V_1 opens upwards. As a result, water from the reservoir tank is pushed up into the cylinder P by the atmospheric pressure acting on the free surface of water in the supply tank. When pump plunger A is pushed downwards by lowering the handle H, the valve V_1 closes due to an increase in pressure in cylinder P. Now pressure from cylinder P is transmitted to the connecting pipe R. As the pressure in pipe R becomes greater than in cylinder Q, the valve V_2 opens, so water from cylinder P is forced into the cylinder Q, due to which the press plunger B is raised against the fixed roof and the bale of cotton placed on the press plunger B gets compressed.

When the function of machine is over, the release valve is opened so that the ram (or press) plunger B gets lowered and water of the cylinder Q runs out into the reservoir.

Uses of hydraulic press : A hydraulic press is used mainly for the following purposes :

1. For pressing cotton bales and goods like quilts, books, etc.
2. For extracting the juice from sugarcane, sugar beet, etc.
3. For squeezing oil out of linseed and cotton seeds.
4. For engraving monograms on goods.

(ii) Hydraulic jack (or Hydraulic lift)

A hydraulic jack is used for lifting heavy vehicles such as cars, trucks etc., in service stations for their repairing. It works on the Pascal's principle (or the principle of a hydraulic machine).

Construction : A simple form of a hydraulic jack is shown in Fig. 4.8. It consists of two cylindrical vessels P and Q connected to each other by a tube R having a valve V. The piston A in the narrow cylinder P is attached to a lever and the piston B of the wider cylinder Q has a platform for lifting the vehicle. The vessels are filled with a liquid (say, water).

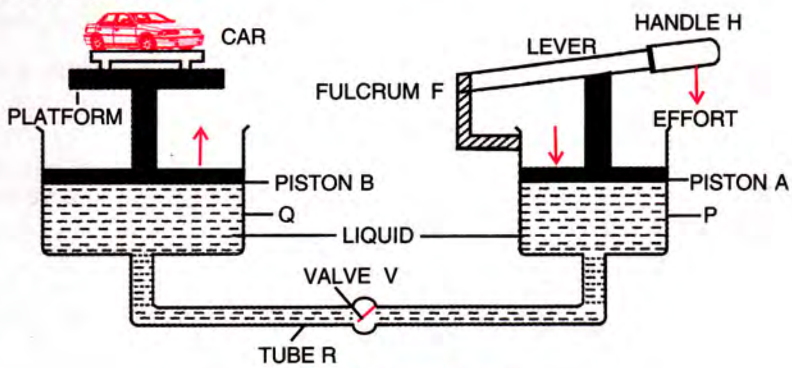


Fig. 4.8 Hydraulic jack

Working : When handle H of lever is pressed down by applying an effort, the valve V opens because of increase in pressure in the cylinder P. The liquid runs out from the cylinder P to the cylinder Q. As a result, the piston B rises up and it raises the car placed on the platform. When the car reaches the desired height, the handle H of lever is no longer pressed. The valve V gets closed (since

the pressure on either side of the valve becomes same) so that the liquid may not run back from the cylinder Q to the cylinder P.

(iii) Hydraulic brakes

The hydraulic brakes used in cars etc., are also based on Pascal's principle.

Construction : Fig. 4.9 shows the hydraulic brake arrangement of a vehicle. It consists of a pipe line R containing a liquid (oil), one end of which is connected to the master cylinder P fitted with a piston A attached to the foot pedal. The other end of pipe R is connected to the brake arrangement of different wheels of the vehicle. Fig. 4.9 shows only one wheel connected with the pipe line. For each wheel, there is a wheel cylinder Q having two pistons B_1 and B_2, attached to the brake shoes. The area of cross section of the wheel cylinder Q is greater than the area of cross section of the master cylinder P. The brake shoes press against the rim of wheel.

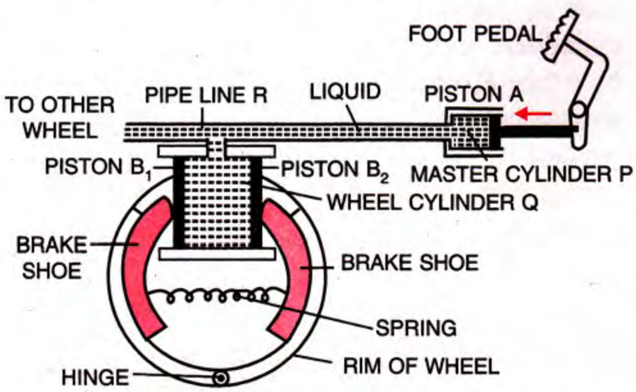


Fig. 4.9 Hydraulic brake

Working : To apply brakes, the foot pedal is pressed due to which pressure is exerted on the liquid in the master cylinder P, so liquid runs out from the master cylinder P to the wheel cylinder Q. As a result, the pressure is transmitted equally and undiminished through the liquid to the pistons B_1 and B_2 of the wheel cylinder Q. Therefore the pistons B_1 and B_2 get pushed outwards and brake shoes get pressed against the rim of the wheel due to which the motion of vehicle retards. Since the area of cross section of piston A in the master cylinder P is less than that in the wheel cylinder Q, a small force applied at the foot pedal produces a large force on the pistons B_1 and B_2 of the wheel cylinder Q. This is the force responsible for retarding the motion of the vehicle. It should be noted that due to transmission of pressure through liquid, equal pressure is exerted on all wheels of the vehicle connected to the pipe line R.

On releasing the pressure on the pedal, the liquid runs back from the wheel cylinder Q to the master cylinder P and the spring pulls the break shoes to their original position and forces the pistons B_1 and B_2 to return back into the wheel cylinder Q. Thus the brakes get released.

Note : In all hydraulic machines, effort is less than load while the distance moved by effort is more than the distance moved by load such that the product of effort and the distance moved by effort is equal to the product of load and the distance moved by load (in ideal situation when there is no energy loss). *i.e.*,

work done by effort = work done by load.

Thus, mechanical advantage (M.A.)

$$= \frac{\text{Load}}{\text{Effort}} > 1$$

and velocity ratio (V.R.)

$$= \frac{\text{distance moved by effort}}{\text{distance moved by load}} > 1$$

Hence a hydraulic machine acts like a *force multiplier*.

EXAMPLES

1. A boy weighing 60 kgf is wearing shoes with heel of area of cross section 20 cm², while a girl weighing 45 kgf is wearing sandals with heel of area of cross section 1·5 cm². Compare the pressure exerted on ground by their heels when they stand on the heel of one foot.

Thrust on heel of boy, $F_1 = 60$ kgf

Area of cross section of heel of boy, $A_1 = 20\text{ cm}^2$

$\therefore$ Pressure exerted by boy, $P_1 = \frac{F_1}{A_1} = \frac{60\text{ kgf}}{20\text{ cm}^2}$

$= 3\text{ kgf cm}^{-2}$ ...(i)

Now thrust on heel of girl, $F_2 = 45$ kgf

Area of cross section of heel of girl, $A_2 = 1{\cdot}5\text{ cm}^2$

$\therefore$ Pressure exerted by girl, $P_2 = \frac{F_2}{A_2} = \frac{45\text{ kgf}}{1{\cdot}5\text{ cm}^2}$

$= 30\text{ kgf cm}^{-2}$ ...(ii)

Hence from eqns, (i) and (ii)

$$\frac{P_2}{P_1} = \frac{30}{3} = \frac{10}{1} = \mathbf{10 : 1}$$

Thus the girl's heel exerts pressure 10 times more than that of the boy's heel.

2. Calculate the pressure due to a water column of height 100 m. (Take g = 10 m s^{-2} and density of water = 10^3 kg m^{-3}).

Given, $h = 100$ m, $\rho = 10^3$ kg m^{-3}, $g = 10$ m s^{-2}

Pressure $= h\rho g$

$= 100 \times 10^3 \times 10 = \mathbf{10^6\ N\ m^{-2}}$.

3. At what depth below the surface of water will pressure be equal to twice the atmospheric pressure ? The atmospheric pressure is 10 N cm^{-2}, density of water is 10^3 kg m^{-3} and g = 9·8 m s^{-2}.

Given, atmospheric pressure $P_0 = 10$ N cm^{-2}

$$= \frac{10\text{ N}}{(10^{-2}\text{ m})^2} = 10^5\text{ N m}^{-2}$$

$\rho = 10^3$ kg m^{-3} and $g = 9{\cdot}8$ m s^{-2}

Pressure at a depth h below the surface of water

= atmospheric pressure

+ pressure due to water column of height h.

or $2P_0 = P_0 + h\rho g$ or $h\rho g = P_0$

Hence $h = \frac{P_0}{\rho g} = \frac{10^5}{10^3 \times 9{\cdot}8} = \mathbf{10{\cdot}2\ m}$

Thus a water column of height 10·2 m exerts a pressure equal to the atmospheric pressure and therefore at depth 10·2 m below the surface of water, the total pressure will be equal to twice the atmospheric pressure.

4. A cube of each side 5 cm is placed inside a liquid. The pressure at the centre of one face of cube is 10 Pa. Calculate the thrust exerted by the liquid on this face.

Given, pressure $P = 10$ Pa,

Area of face $A = 5\text{ cm} \times 5\text{ cm} = \frac{5}{100}\text{ m} \times \frac{5}{100}\text{ m}$

$= 25 \times 10^{-4}$ m^2.

The thrust exerted by the liquid on the face

$F = P \times A = 10\text{ Pa} \times (25 \times 10^{-4})\text{ m}^2 = \mathbf{2{\cdot}5 \times 10^{-2}\ N}$.

5. A square plate of side 10 m is placed horizontally 1 m below the surface of water. The atmospheric pressure is 1·013 × 10^5 N m^{-2}. Calculate the total thrust on the plate.

(Density of water ρ = 10^3 kg m^{-3}, g = 9·8 m s^{-2})

Given, $h = 1$ m, $\rho = 10^3$ kg m^{-3}, $g = 9{\cdot}8$ m s^{-2}

Atmospheric pressure $P_0 = 1{\cdot}013 \times 10^5$ N m^{-2},

area of plate = 10 m × 10 m = 10^2 m^2.

Total pressure at a point below the surface of water = atmospheric pressure + pressure due to the column of water

$= P_0 + h\rho g$

$= (1{\cdot}013 \times 10^5) + (1 \times 10^3 \times 9{\cdot}8)$

$= 1{\cdot}111 \times 10^5$ N m^{-2}

∴ Total thrust on the plate = Pressure × Area of plate

$= (1{\cdot}111 \times 10^5) \times 10^2$

$= \mathbf{1{\cdot}111 \times 10^7\ N}$.

6. A vessel of base area 100 cm × 60 cm and height 200 cm is completely filled with a liquid of density 1·1 × 10^3 kg m^{-3}.

(a) Ignoring the atmospheric pressure, find :

(i) the thrust at the bottom of the vessel,

(ii) the pressure at the bottom of the vessel,

(iii) the pressure at a depth of 5 cm from the free surface,

(iv) the net force experienced by a metal foil of area 10 cm^2 placed at a depth of 5 cm from the free surface,

(b) The thrust at the bottom of the vessel if the atmospheric pressure equal to 1 × 10^5 N m^{-2} is taken into account. Take g = 9·8 m s^{-2}.

(a) Given, area of base of vessel = 100 cm × 60 cm,

$$= \frac{100}{100}\text{ m} \times \frac{60}{100}\text{ m} = 0{\cdot}6\text{ m}^2$$

height = 200 cm, $\rho = 1{\cdot}1 \times 10^3$ kg m^{-3}, $g = 9{\cdot}8$ m s^{-2}

Volume of the vessel = 100 cm × 60 cm × 200 cm

$$= \frac{100}{100}\text{ m} \times \frac{60}{100}\text{ m} \times \frac{200}{100}\text{ m}$$

$= 1{\cdot}2$ m^3

(i) Thrust at the bottom of the vessel

= Weight of liquid in the vessel

= Volume × density $\rho \times g$

$= 1{\cdot}2 \times (1{\cdot}1 \times 10^3) \times 9{\cdot}8$

$= \mathbf{1{\cdot}294 \times 10^4\ N}$

(ii) Pressure at the bottom of the vessel $= \frac{\text{Thrust}}{\text{Area}}$

$$= \frac{1{\cdot}294 \times 10^4\text{ N}}{0{\cdot}6\text{ m}^2} = \mathbf{2{\cdot}16 \times 10^4\ N\ m^{-2}}$$

(iii) Pressure at a depth of 5 cm (= 0·05 m) from the free surface

$= h\rho g = 0{\cdot}05 \times (1{\cdot}1 \times 10^3) \times 9{\cdot}8 = \mathbf{539\ N\ m^{-2}}$

(iv) Net force on the metal foil will be **zero** because the force exerted by the liquid on each of the two faces (upper and lower) of foil, will be equal and opposite.

(b) Total pressure at the bottom of vessel = Atmospheric pressure + pressure at the bottom due to liquid column

$= (1{\cdot}0 \times 10^5) + (2{\cdot}16 \times 10^4)$

$= (1{\cdot}0 \times 10^5) + (0{\cdot}216 \times 10^5)$

$= 1{\cdot}216 \times 10^5$ N m^{-2}

$\therefore$ Total thrust at the bottom = Pressure × Area

$= (1{\cdot}216 \times 10^5) \times 0{\cdot}6 = \mathbf{7{\cdot}296 \times 10^4}$ **N.**

7. In Fig. 4.10, a tube of length 200 cm filled with a liquid of density $0{\cdot}90 \times 10^3$ kg m^{-3} is placed inclined with the vertical such that the level *A* of liquid in the tube is at a vertical height 100 cm from its lowest point *C*. There is a point *B* in the tube below the point *A* at a vertical depth 60 cm.

(a) Calculate the pressure at points (i) *A*, (ii) *B* and (iii) *C*.

(b) What will be the pressure at point *C* when the tube is made vertical ?

Take atmospheric pressure = $1{\cdot}013 \times 10^5$ N m^{-2}.

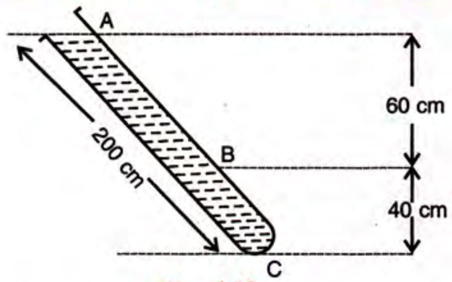


Fig. 4.10

Given, $\rho = 0{\cdot}9 \times 10^3$ kg m^{-3}, $P_0 = 1{\cdot}013 \times 10^5$ N m^{-2}, $g = 9{\cdot}8$ m s^{-2}

(a) (i) At the point *A*,

Pressure = Atmospheric pressure (P_0)

$= \mathbf{1{\cdot}013 \times 10^5}$ **N m^{-2}**

(ii) At the point *B*,

Pressure = Atmospheric pressure + pressure due to liquid column of vertical height 60 cm ($h = 0{\cdot}6$ m)

$= P_0 + h\rho g$

$= (1{\cdot}013 \times 10^5) + [0{\cdot}6 \times (0{\cdot}9 \times 10^3) \times 9{\cdot}8]$

$= (1{\cdot}013 \times 10^5) + (0{\cdot}053 \times 10^5)$

$= \mathbf{1{\cdot}066 \times 10^5}$ **N m^{-2}**

(iii) At the point *C*,

Pressure = Atmospheric pressure + pressure due to liquid column of vertical height 100 cm ($h = 1$ m)

$= (1{\cdot}013 \times 10^5) + [1 \times (0{\cdot}9 \times 10^3) \times 9{\cdot}8]$

$= (1{\cdot}013 \times 10^5) + (0{\cdot}0882 \times 10^5)$

$= \mathbf{1{\cdot}101 \times 10^5}$ **N m^{-2}.**

(b) On making the tube vertical, at the point *C*,

Pressure = Atmospheric pressure + pressure due to liquid column of height 200 cm ($h = 2$ m),

$= (1{\cdot}013 \times 10^5) + [2 \times (0{\cdot}9 \times 10^3) \times 9{\cdot}8]$

$= (1{\cdot}013 \times 10^5) + (0{\cdot}1764 \times 10^5)$

$= \mathbf{1{\cdot}189 \times 10^5}$ **N m^{-2}.**

8. A U tube is first partially filled with mercury. Then water is added in one arm and an oil is added in the other arm. Find the ratio of water and oil columns so that mercury level is same in both the arms of U tube. Given : density of water = 10^3 kg m^{-3}, density of oil = 900 kg m^{-3}.

Since level of mercury is same in both the arms of the U tube, therefore

Pressure of water column on the surface of mercury in one arm = Pressure of oil column on the surface of mercury in the other arm. *i.e.,*

$$h_1\rho_1 g = h_2 \rho_2 g$$

where h_1 = height of water column,

ρ_1 = density of water = 10^3 kg m^{-3},

h_2 = height of oil column, and

ρ_2 = density of oil = 900 kg m^{-3}.

$$\therefore \quad \frac{h_1}{h_2} = \frac{\rho_2}{\rho_1} = \frac{900}{10^3} = \mathbf{\frac{9}{10}}$$

9. Fig. 4.11 shows a cube of each side 15 cm immersed in a tub containing water of density 10^3 kg m^{-3} such that its top surface is 20 cm below the free surface of water.

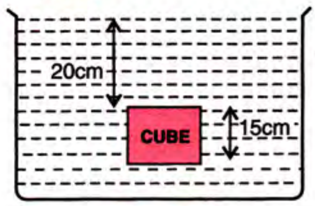


Fig. 4.11

Calculate :

(i) the pressure at the top of cube,

(ii) the pressure at the bottom of cube,

(iii) the resultant pressure on cube.

(iv) the resultant thrust on cube.

Take atmospheric pressure = 10^5 Pa and $g = 9{\cdot}8$ N kg^{-1}.

Given, atmospheric pressure $P_0 = 10^5$ Pa, $g = 9{\cdot}8$ N kg^{-1}, depth of top of the cube from the free surface of water $h_1 = 20$ cm $= 0{\cdot}2$ m, depth of bottom of cube from the free surface of water $h_2 = (20 + 15)$ cm $= 35$ cm $= 0{\cdot}35$ m

(i) Pressure at the top surface of cube

$P_1 = P_0 + h_1\rho g$

$= 10^5 + (0{\cdot}20 \times 10^3 \times 9{\cdot}8)$

$= \mathbf{1{\cdot}0196 \times 10^5}$ **Pa**

(ii) Pressure at the bottom surface of cube

$P_2 = P_0 + h_2\rho g$

$= 10^5 + (0{\cdot}35 \times 10^3 \times 9{\cdot}8)$

$= \mathbf{1{\cdot}0343 \times 10^5}$ **Pa**

(iii) Resultant pressure on cube

$= P_2 - P_1 = 1{\cdot}0343 \times 10^5 - 1{\cdot}0196 \times 10^5$

$= 0{\cdot}0147 \times 10^5$ Pa (or $\mathbf{1{\cdot}47 \times 10^3}$ **Pa**).

(iv) Area of base of cube

= 15 cm × 15 cm

$= \frac{15}{100}\text{ m} \times \frac{15}{100}\text{ m} = 225 \times 10^{-4}\text{ m}^2$

$\therefore$ Resultant thrust on cube

$= $ Resultant pressure × area of base

$= (1{\cdot}47 \times 10^3) \times (225 \times 10^{-4})$

$=$ **33·074 N (upwards)**

Note: The resultant pressure on cube will be upwards. The resultant thrust acting on cube in upward direction is called upthrust. Obviously this upthrust depends on the immersed volume (= area of base × height) of the cube and not on its depth inside water. Here we can note that if cube is replaced by a lamina which has negligible thickness ($h \to 0$), pressure on the two sides of lamina will be equal, hence upthrust on it will be zero.

10. An air bubble rises from the bottom of a lake of depth 10·34 m to its surface. Compare the pressure on bubble at the bottom to that on surface. (Atmospheric pressure = 0·76 m of Hg, density of Hg = 13·6 × 10³ kg m⁻³ and density of water = 10³ kg m⁻³).

Given, Atmospheric pressure $P_0 = 0{\cdot}76$ of Hg

$= 0{\cdot}76 \times (13{\cdot}6 \times 10^3) \times 9{\cdot}8 = 1{\cdot}013 \times 10^5$ N m^{-2}

$h = 10{\cdot}34$ m, $\rho = 10^3$ kg m^{-3}, $g = 9{\cdot}8$ m s^{-2}

Pressure on bubble at the bottom of lake

P_1 = Atmospheric pressure + pressure due to water column

$= P_0 + h\rho g$

$= (1{\cdot}013 \times 10^5) + (10{\cdot}34 \times 10^3 \times 9{\cdot}8)$

$= 2{\cdot}026 \times 10^5$ N m^{-2} ...(i)

Pressure on bubble at the surface of lake

P_2 = Atmospheric pressure P_0

$= 1{\cdot}013 \times 10^5$ N m^{-2} ...(ii)

From eqns. (i) and (ii)

$$\frac{P_1}{P_2} = \frac{2{\cdot}026 \times 10^5}{1{\cdot}013 \times 10^5} = \frac{\mathbf{2}}{\mathbf{1}}$$

11. In a hydraulic machine, the two pistons are of area of cross section in the ratio 1 : 10. What force is needed on the narrow piston to overcome a force of 100 N on the wider piston ?

Given, $A_1 : A_2 = 1 : 10$, $F_1 = ?$, $F_2 = 100$ N

By the principle of hydraulic machine

Pressure on narrow piston = Pressure on wider piston

or $$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$\therefore \quad F_1 = F_2 \times \frac{A_1}{A_2} = 100 \times \frac{1}{10} = \mathbf{10\ N.}$$

12. The area of cross section of press plunger of a hydraulic press is 4 m². It is required to overcome a resistive load of 400 kgf on it. Calculate the force required on the pump plunger if the area of cross section of the pump plunger is 0·01 m².

Let F be the force required on the pump plunger.

Given, for pump plunger $F_1 = F$, $A_1 = 0{\cdot}01$ m², for press plunger $F_2 = 400$ kgf, $A_2 = 4$ m².

By Pascal's law,

Pressure on pump plunger

= Pressure on press plunger.

or $$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

i.e., $$\frac{F}{0{\cdot}01} = \frac{400}{4}$$

$\therefore \quad F = 100 \times 0{\cdot}01 = 1$ kgf.

i.e., Force required on pump plunger = **1 kgf.**

EXERCISE 4 (A)

1. Define the term thrust. State its S.I. unit.
2. What is meant by pressure ? State its S.I. unit.
3. (a) What physical quantity is measured in bar ?
   (b) How is the unit bar related to the S.I. unit pascal ?
   Ans. (a) Pressure, (b) 1 bar = 10^5 pascal
4. Define one pascal (Pa), the S.I. unit of pressure.
5. State whether thrust is a scalar or vector ?
   Ans. Vector
6. State whether pressure is a scalar or vector ?
   Ans. Scalar
7. Differentiate between thrust and pressure.
8. How does the pressure exerted by a thrust depend on the area of surface on which it acts ? Explain with a suitable example.
9. Why is the tip of an allpin made sharp ?
10. Explain the following :
    (a) It is easier to cut with a sharp knife than with a blunt one.
    (b) Sleepers are laid below the rails.
11. What is a fluid ?
12. What do you mean by the term fluid pressure ?

13. How does the pressure exerted by a solid and a fluid differ ?

Ans. A solid exerts pressure only on its base downwards while a fluid exerts pressure at all points in all directions.

14. Describe a simple experiment to demonstrate that a liquid enclosed in a vessel exerts pressure in all directions.

15. State *three* factors on which the pressure at a point in a liquid depends.

16. Write an expression for the pressure at a point inside a liquid. Explain the meaning of the symbols used.

17. Deduce an expression for the pressure at a depth inside a liquid.

18. How does the pressure at a certain depth in sea water differ from that at the same depth in river water ? Explain your answer.

19. Pressure at free surface of a water lake is P_1, while at a point at depth h below its free surface is P_2. (a) How are P_1 and P_2 related ? (b) Which is more P_1 or P_2 ?

Ans. (a) $P_2 = P_1 + h\rho g$, (b) $P_2 > P_1$

20. Explain why a gas bubble released at the bottom of a lake grows in size as it rises to the surface of lake.

21. A dam has broader walls at the bottom than at the top. Explain.

22. Why do sea divers need special protective suit ?

23. State the laws of liquid pressure.

24. A tall vertical cylinder filled with water is kept on a horizontal table top. Two small holes A and B are made on the wall of the cylinder, A near the middle and B just below the free surface of water. State and explain your observation.

25. How does the liquid pressure on a diver change if :

(i) the diver moves to the greater depth, and

(ii) the diver moves horizontally ?

Ans. (i) Pressure increases, (ii) Pressure remains unchanged

26. State Pascal's law of transmission of pressure.

27. Name *two* applications of Pascal's law.

28. Explain the principle of a hydraulic machine. Name *two* devices which work on this principle.

29. Name and state the principle on which a hydraulic press works. Write *one* use of the hydraulic press.

30. The diagram in Fig. 4.12 shows a device which makes use of the principle of transmission of pressure.

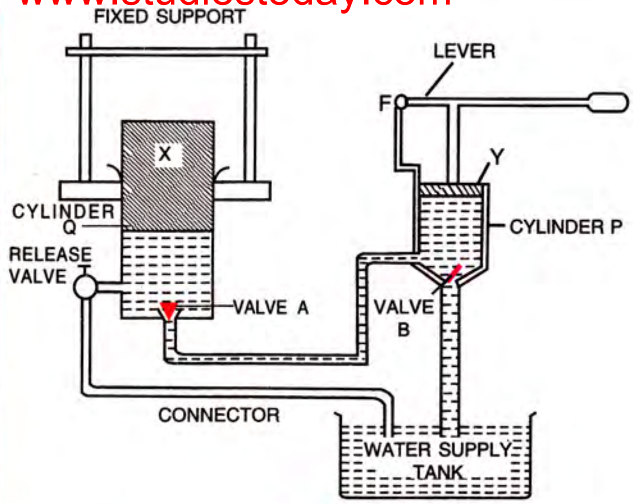


Fig. 4.12

(i) Name the parts labelled by the letters X and Y.

(ii) Describe what happens to the valves A and B and to the quantity of water in the two cylinders when the lever arm is moved down.

(iii) Give reasons for what happens to the valves A and B in part (ii).

(iv) What happens when the release valve is opened ?

(v) What happens to the valve B in cylinder P when the lever arm is moved up ?

(vi) Give a reason for your answer in part (v).

(vii) State *one* use of the above device.

31. Draw a simple diagram of a hydraulic jack and explain its working.

32. Explain the working of a hydraulic brake with a simple labelled diagram.

33. Complete the following sentences :

(a) Pressure at a depth h in a liquid of density ρ is ....

(b) Pressure is.................... in all directions about a point in a liquid.

(c) Pressure at all points at the same depth is....................

(d) Pressure at a point inside a liquid is .... to its depth.

(e) Pressure of a liquid at a given depth is .... to the density of liquid.

Ans. (a) $h\rho g$ (b) same (c) same (d) directly proportional (e) directly proportional.

Multiple Choice Type :

1. The S.I. unit of pressure is :

(a) N cm^{-2} (b) Pa

(c) N (d) N m^2

Ans. (b) Pa

2. The pressure inside a liquid of density ρ at a depth h is :

(a) $h\rho g$ (b) $\frac{h}{\rho g}$

(c) $\frac{h\rho}{g}$ (d) $h\rho$

Ans. (a) $h\rho g$

3. The pressure P_1 at a certain depth in river water and P_2 at the same depth in sea water are related as :

(a) $P_1 > P_2$ (b) $P_1 = P_2$

(c) $P_1 < P_2$ (d) $P_1 - P_2$ = atmospheric pressure

Ans. (c) $P_1 < P_2$

4. The pressure P_1 at the top of a dam and P_2 at a depth h from the top inside water (density ρ) are related as :

(a) $P_1 > P_2$ (b) $P_1 = P_2$

(c) $P_1 - P_2 = h \rho g$ (d) $P_2 - P_1 = h\rho g$

Ans. (d) $P_2 - P_1 = h\rho g$

Numericals :

1. A hammer exerts a force of 1·5 N on each of the two nails A and B. The area of cross section of tip of nail A is 2 mm² while that of nail B is 6 mm². Calculate pressure on each nail in pascal.

Ans. On ***A*** : $7{\cdot}5 \times 10^5$ pascal, On ***B*** : $2{\cdot}5 \times 10^5$ pascal.

2. A block of iron of mass 7·5 kg and of dimensions 12 cm × 8 cm × 10 cm is kept on a table top on its base of side 12 cm × 8 cm. Calculate : (a) thrust and (b) pressure exerted on the table top. Take 1 kgf = 10 N. **Ans.** (a) 75 N (b) 7812·5 Pa

3. A vessel contains water up to a height of 1·5 m. Taking the density of water 10^3 kg m^{-3}, acceleration due to gravity 9·8 m s^{-2} and area of base of vessel 100 cm², calculate : (a) the pressure and (b) the thrust, at the base of vessel.

Ans. (a) $1{\cdot}47 \times 10^4$ N m^{-2} (b) 147 N

4. The area of base of a cylindrical vessel is 300 cm². Water (density = 1000 kg m^{-3}) is poured into it up to a depth of 6 cm. Calculate : (a) the pressure and (b) the thrust of water on the base. (g = 10 m s^{-2}).

Ans. (a) 600 Pa, (b) 18 N

5. (a) Calculate the height of a water column which will exert on its base the same pressure as the 70 cm column of mercury. Density of mercury is 13·6 g cm^{-3}.

(b) Will the height of the water column in part (a) change if the cross section of the water column is made wider ?

Ans. (a) 9·52 m (b) No

6. The pressure of water on the ground floor is 40,000 Pa and on the first floor is 10,000 Pa. Find the height of the first floor.
(Take : density of water = 1000 kg m^{-3}, g = 10 m s^{-2})

Ans. 3 m

7. A simple U tube contains mercury to the same level in both of its arms. If water is poured to a height of 13·6 cm in one arm, how much will be the rise in mercury level in the other arm ?

Given : density of mercury = $13{\cdot}6 \times 10^3$ kg m^{-3} and density of water = 10^3 kg m^{-3}. **Ans.** 1 cm

8. In a hydraulic machine, a force of 2 N is applied on the piston of area of cross section 10 cm². What force is obtained on its piston of area of cross section 100 cm²? **Ans.** 20 N

9. What should be the ratio of area of cross section of the master cylinder and wheel cylinder of a hydraulic brake so that a force of 15 N can be obtained at each of its brake shoe by exerting a force of 0·5 N on the pedal ? **Ans.** 1 : 30

10. The areas of pistons in a hydraulic machine are 5 cm² and 625 cm². What force on the smaller piston will support a load of 1250 N on the larger piston ? State any assumption which you make in your calculation. **Ans.** 10 N

Assumption : There is no friction and no leakage of liquid.

11. (a) The diameter of neck and bottom of a bottle are 2 cm and 10 cm respectively. The bottle is completely filled with oil. If the cork in the neck is pressed in with a force of 1·2 kgf, what force is exerted on the bottom of the bottle ?

(b) Name the law/principle you have used to find the force in part (a)

Ans. (a) 30 kgf (b) Pascal's law

12. A force of 50 kgf is applied to the smaller piston of a hydraulic machine. Neglecting friction, find the force exerted on the large piston, if the diameters of the pistons are 5 cm and 25 cm respectively. **Ans.** 1250 kgf

13. Two cylindrical vessels fitted with pistons A and B of area of cross section 8 cm² and 320 cm² respectively, are joined at their bottom by a tube and they are completely filled with water. When a mass of 4 kg is placed on piston A, find : (i) the pressure on piston A, (ii) the pressure on piston B, and (iii) the thrust on piston B.

Ans. (i) 0·5 kgf cm^{-2}, (ii) 0·5 kgf cm^{-2} (iii) 160 kgf

14. What force is applied on a piston of area of cross section 2 cm² to obtain a force 150 N on the piston of area of cross section 12 cm² in a hydraulic machine ? **Ans.** 25 N

(B) ATMOSPHERIC PRESSURE AND ITS MEASUREMENT

4.9 ATMOSPHERIC PRESSURE

The earth is surrounded by air up to a height of about 300 km from its surface. This envelope of air around the earth is called ***atmosphere***. The weight of air column exerts a thrust on the earth surface. The thrust exerted on unit area of the earth surface is called the atmospheric pressure. Thus

The thrust exerted per unit area on the earth surface due to column of air, is called the atmospheric pressure on the surface of earth.

Note : The weight of air column over 1 cm^2 area on the earth surface is nearly 1 kgf, so the atmospheric pressure on the earth surface is about 1 kgf per cm^2 (= 1 kgf/1 cm^2 = 10 N/10^{-4} m^2 = 10^5 N m^{-2}). This implies that a thrust of about 100,000 N acts on every 1 m^2 of the surface of objects on the earth. The average surface area of a human body is about 2 m^2, therefore the atmosphere exerts a total thrust of about 2×10^5 N on our body. However, we are not aware of this enormous thrust (or load) on us because the pressure of our blood (*i.e., blood pressure*), balances it. The blood pressure is slightly more than the atmospheric pressure. However, at high altitude, the atmospheric pressure becomes less because the height of air column above that altitude is less than at the earth surface. As a result, at high altitudes the blood pressure becomes much more than the atmospheric pressure and nose bleeding may occur due to excess blood pressure.

4.10 DEMONSTRATION OF ATMOSPHERIC PRESSURE

The existence of atmospheric pressure can be easily demonstrated in laboratory by the following simple experiment.

Collapsing tin can experiment

Take a thin tin can fitted with an airtight stopper. The stopper is removed and a small quantity of water is boiled in the can. Gradually the steam occupies the entire space of can by expelling the air from it [Fig 4.13(a)]. The stopper is then tightly replaced and simultaneously the flame beneath the can is removed. Cold water is then poured over the can. It is observed that the can collapses inwards as shown in Fig 4.13(b). The reason is that initially the pressure due to steam inside the heated can is same as the air pressure outside the can [Fig. 4.13(a)]. But on pouring cold water over the can, fitted with a stopper [Fig. 4.13(b)], the steam inside the can condenses, producing water and water vapours at a very low pressure. Now the air pressure outside the can exceeds the vapour pressure inside the closed can. Consequently, the excess atmospheric pressure outside the can causes it to collapse inwards. This demonstrates that the atmosphere outside the can exerts a pressure which is the atmospheric pressure.

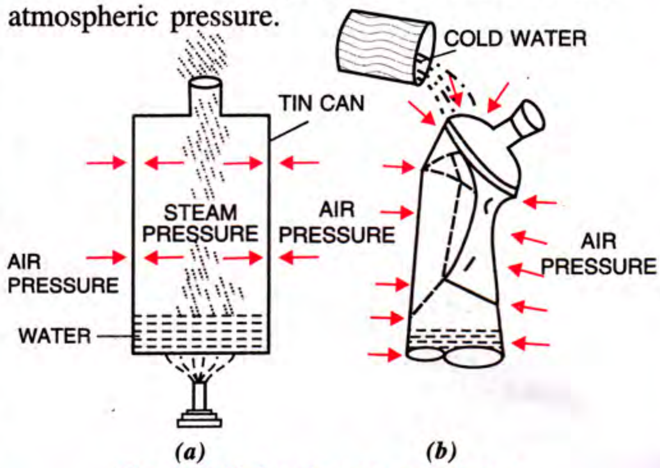


Fig. 4.13 Collapsing can experiment

4.11 COMMON CONSEQUENCES OF THE ATMOSPHERIC PRESSURE

(i) **Sucking a drink with a straw :** When a drink is sucked with a straw (Fig 4.14), first the air in straw goes into our lungs due to which the air pressure inside the straw decreases. The atmospheric pressure acting on the surface of drink being more than the pressure inside the straw, forces the drink to move up into the straw which then reaches into our mouth.

Fig. 4.14 Sucking a drink with a straw

(ii) Filling a syringe with a liquid : When syringe is kept with its opening just inside a liquid and its plunger is pulled up in the barrel (Fig. 4.15), the pressure of air inside the barrel below the plunger becomes much less than the atmospheric pressure acting on the liquid. As a result, the atmospheric pressure forces the liquid to rise up in the syringe.

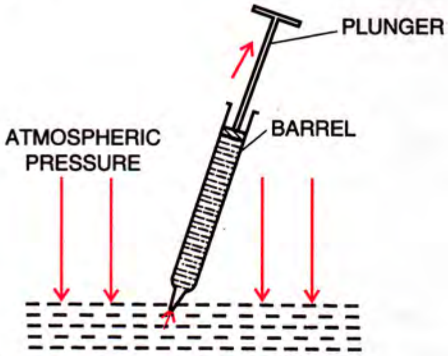


Fig. 4.15 Action of syringe

In a similar manner, in a water pump, water is drawn up from a well on pulling the piston up.

(iii) Filling of ink into a fountain pen : As a syringe is filled with a liquid due to the atmospheric pressure, ink also gets filled into a fountain pen. The pen is kept with its nib inside ink. When the rubber tube of fountain pen is pressed, almost all the air of rubber tube expels out in form of bubbles through the ink. When the rubber tube is released, the pressure inside the rubber tube is much less than the atmospheric pressure acting on the ink. As a result, the ink rises into the tube through the capillary below the nib of the pen.

(iv) Action of rubber suckers : Rubber suckers are often used as hooks in the kitchen and bathroom. For this, rubber sucker is pressed hard against the wall (Fig. 4.16) so that the air between the sucker and the wall is forced out, creating a vacuum in between. The atmospheric pressure acting on it from outside then holds the sucker alongwith the hook on it firmly against the wall. For firm grip, the wall must be smooth.

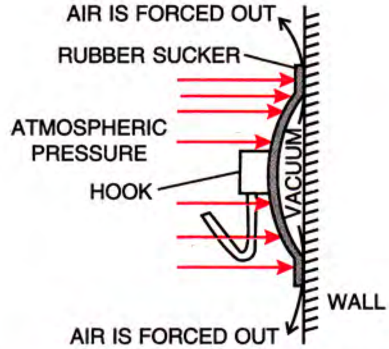


Fig. 4.16 Action of rubber sucker

(v) Action of a siphon system : Water is supplied from a higher level to a lower level using a siphon system. Fig. 4.17 shows the siphon system in which there are two vessels P and Q. Vessel P is at a higher level than the vessel Q. Water contained in the vessel P is passed to the vessel Q by means of a glass (or rubber) tube AB with one end A kept immersed inside water in vessel P, while the other end B is kept open in vessel Q. To transfer water from vessel P to vessel Q, first air is sucked out from the tube at the lower end B of it, so that pressure inside the tube decreases. It becomes less than the atmospheric pressure acting above the water surface in vessel P. Due to excess presure at A, water rises in the tube through the end A, so as to reach up to the level C. Then water flows down through the tube from the higher level C to the lower level B in the vessel Q due to the difference in pressure of water at the levels C and B.

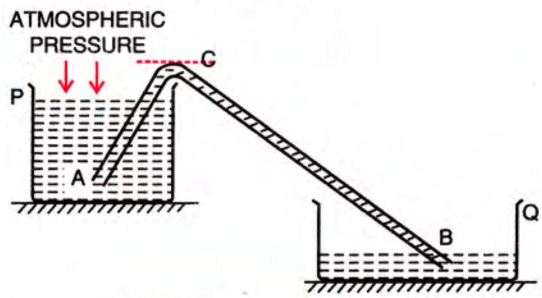


Fig. 4.17 Siphon system

(vi) Taking out oil from a sealed oil can : It is difficult to take out oil from a *completely filled and sealed can* by making a single hole in it. The reason is that there is no air inside a completely filled and sealed oil can. When the can is tilted, the pressure due to the column of oil (inside the can) at the hole is much less than

the atmospheric pressure outside the can, so the oil does not flow out of the hole. But if one more hole is made at the opposite end on the top cover of the can, air outside the can will enter in through this hole and will exert atmospheric pressure on the oil from inside alongwith the pressure due to oil column. This results in the increase in pressure on oil, and so it easily flows out through the hole of the can.

4.12 MEASUREMENT OF ATMOSPHERIC PRESSURE

Atmospheric pressure at a place is measured by a *barometer*. Thus

A barometer is an instrument which is used to measure the atmospheric pressure.

The following *three* types of barometers are commonly used :

(i) Simple barometer (ii) Fortin's barometer (iii) Aneroid barometer

(i) Simple barometer

In 1643, Torricelli first designed a *simple barometer* using mercury as the barometric liquid.

Construction : A simple barometer has a hard glass tube of about 1 m length closed at one end. The tube is completely filled with pure mercury such that no air bubble remains inside the tube. The open end of tube is closed with thumb and the tube is then made upside down several times so as to force out any air bubble which might have entered in it. The completely filled tube with its open end closed by thumb is then inverted into a trough of mercury in such a way that the open end of tube is well immersed in mercury and the tube stands vertical as shown in Fig. 4.18. Now the thumb is removed. Care is taken that no air enters in the glass tube.

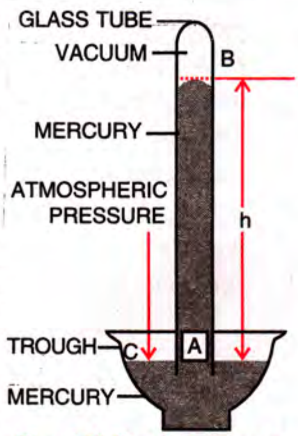


Fig. 4.18 Simple barometer

It is seen that the mercury level in tube falls till its height above the mercury level in the trough becomes h (= nearly 76 cm) as shown in Fig. 4.18.

Explanation : In Fig 4.18, the atmospheric pressure acts at all points (such as C) on the surface of mercury in the trough. The pressure at point A is due to the weight (or thrust) of the mercury column AB above it. When mercury level in the tube becomes stationary, the pressure inside tube at the point A which is at the level of the point C, must be same as that at the point C. Thus the vertical height of mercury column in it (*i.e.*, $AB = h$) is called the *barometric height*. The space left empty above the mercury column in the tube is called the *torricellian vacuum*. Ideally there should be no air in this space.

Working : If the atmospheric pressure increases, the pressure at point C increases and mercury from trough flows into the tube thereby increasing the vertical height of mercury column in the tube so as to equalise pressures at the points A and C. On the other hand, when the atmospheric pressure decreases, the vertical height of the column in tube decreases to balance it. Thus, *the vertical height of mercury column from the mercury surface in trough to the level in tube, is a measure of the atmospheric pressure.*

Barometric height at normal temperature and pressure : The barometric height at normal temperature and pressure at sea level is 0·76 m (or 76 cm or 760 mm) of mercury.

Factors affecting the barometric height : The barometric height at a place changes only when the atmospheric pressure at that place changes.

Note : **(1)** The barometric height remains *same* even when the shape of tube is changed or the length of tube submerged inside mercury in the trough is changed or tube is tilted from its vertical position as shown in Fig 4.19.

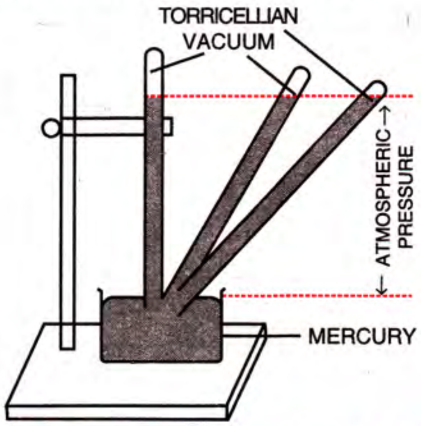


Fig. 4.19 Tilting of the barometer tube

(2) In an accurate (or true) barometer, the empty space above the mercury column in tube is perfect *vacuum*. If somehow air enters the empty space or a drop of water (or liquid) gets into the tube, it will immediately change into vapour in the vacuum space and the air (or the vapours of liquid) will exert pressure on the mercury column due to which the barometric height will decrease. Such a barometer is a *faulty barometer*. The barometric height of a faulty barometer will be less than the actual atmospheric pressure.

Advantages of using mercury as a barometric liquid

A barometre can be made by using any liquid, but the use of mercury as a barometric liquid is preferred for the following reasons :

1. The density of mercury ($= 13{\cdot}6 \times 10^3$ kg m^{-3}) is greater than that of any other liquid, so only 0·76 m height of mercury column is needed to balance the normal atmospheric pressure. Use of other liquids require much longer tube.
2. The vapour pressure of mercury is negligible, so the vapours in the torricellian vacuum does not affect the barometric height.
3. The mercury neither wets nor sticks to the glass tube therefore it gives the accurate reading.
4. The surface of mercury is shining and opaque. Therefore, it is easily seen while taking the observation.
5. It can easily be obtained in a pure state.

Disadvantages of using water as a barometric liquid

If water is used in a barometer, it has the following disadvantges :

1. The density of water is low ($= 10^3$ kg m^{-3}), so nearly 10·4 m height of water column is needed to balance the normal atmospheric pressure. But it is highly inconvenient to take a tube of height 10·4 m for a barometer.
2. The vapour pressure of water is high, so its vapours in the vacuum space will make the reading inaccurate.
3. Water sticks with the glass tube and wets it, so the reading becomes inaccurate.
4. Water is transparent, so its surface is not easily seen while taking the observation.

Demerits of a simple barometer

(i) There is no protection for the glass tube.

(ii) The surface of mercury in the trough is open therefore there are chances that the impurities may fall in and get mixed with the mercury of the trough.

(iii) It is inconvenient to move the barometer from one place to another *i.e.* it is not portable.

(iv) A scale can not be fixed with the tube (or it can not be marked on the tube) to measure the atmospheric pressure. The reason is that when the atmospheric pressure changes, the height of mercury column in the tube changes. As a result, the level of free surface of mercury in the trough changes due to the flow of mercury in or out of the tube. Therefore, the free surface of mercury in trough will not remain coinciding with the zero mark of scale if a scale is fixed with it to measure the barometric height.

The above demerits have been removed in the *Fortin barometer.*

(ii) Fortin barometer

The Fortin barometer is a modified form of a simple barometer. It is used in laboratory to measure the atmospheric pressure. It also uses mercury as the barometric liquid.

Construction : The Fortin barometer shown in Fig. 4.20 consists of a narrow glass tube of length about 85 cm to 90 cm. This tube is closed at one end and has a opening at the other end. It is completely filled with pure mercury and is kept inverted in a glass vessel having a leather cup at the bottom. The cup contains mercury and behaves like a trough. The open end of tube is dipped into mercury of the cup. The glass tube is protected by enclosing it in a brass case. At the bottom of the brass case, there is a screw *S*, the end of which supports the leather cup of the glass vessel. The leather cup can be raised up or lowered down with the help of the screw *S* to adjust the mercury level in the glass vessel. The mercury level in the glass vessel is adjusted to coincide with the zero mark of the main scale graduated in mm attached with the brass tube. The zero mark of the fixed scale is

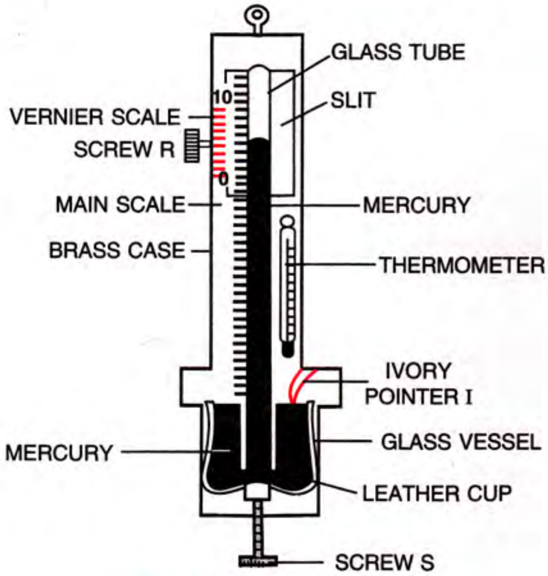


Fig. 4.20 Fortin barometer

at the tip of an ivory pointer *I* which is distinctly visible from outside. The upper part of the brass tube has a slit in it so as to note the mercury level in the glass tube. For accurate measurement, a vernier scale is provided which slides over the main scale by using the screw *R*. A thermometer *T* is also mounted on the case which records the room temperature.

Measurement : To measure the atmospheric pressure, first the level of mercury in the leather cup is raised up or lowered down with the help of the screw *S* so that the mercury level in the glass vessel just touches the ivory point *I*. The position of mercury level in the barometer tube is noted with the help of the main scale and the vernier scale. The sum of vernier scale reading and the main scale reading gives the barometric height.

(iii) Aneroid barometer

This barometer has no liquid. It is light and portable and therefore, it can easily be carried from one place to another. It is calibrated to read directly the atmospheric pressure. It needs no prior adjustment like Fortin barometer.

Construction : Fig. 4.21 (a) shows the main parts of an aneroid barometer. It consists of a metallic box *B* which is partially evacuated. The top *D* of box is springy and is corrugated in form of a diaphragm as shown in Fig. 4.21 (b). At the middle of diaphragm, there is a thin rod *L* toothed at its upper end. The teeth of rod fit well into the teeth of a wheel *S* attached with a pointer *P* which can slide over a circular scale. The circular scale is graduated and is *initially calibrated* with a standard barometer so as to read the atmospheric pressure directly in terms of the barometric height.

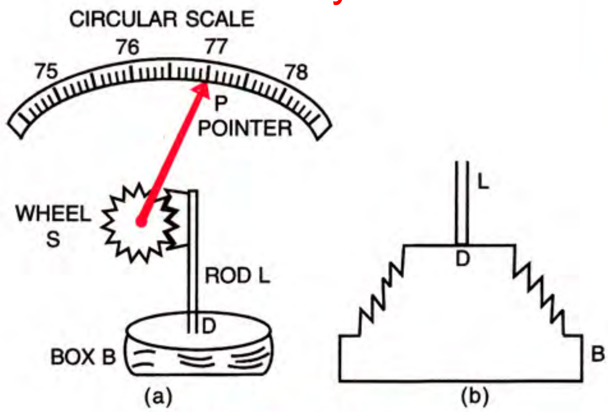


Fig. 4.21 Aneroid barometer

Working : When atmospheric pressure increases, it presses the diaphragm *D* and the rod *L* gets depressed. The wheel *S* rotates clockwise and pointer *P* moves to the right on the circular scale. On the other hand, when atmospheric pressure decreases, the diaphragm *D* bulges out due to which the rod *L* moves up and the wheel *S* rotates anti-clockwise. Consequently, the pointer moves to the left.

Uses of a barometer

A barometer is used for the following *three* purposes:

1. To measure the atmospheric pressure at a place.
2. For weather forecasting.
3. As an altimeter to measure the height.

4.13 VARIATION OF ATMOSPHERIC PRESSURE WITH ALTITUDE

The atmospheric pressure decreases with altitude mainly due to the following *two* factors:

(i) decrease in height of air column which causes a *linear* decrease in the atmospheric pressure,

(ii) decrease in density of air which causes a *non-linear** decrease in atmospheric pressure.

* The decrease in density of air with altitude is not linear. It is rapid at low altitude but slow at high altitude.

(i) The atmosphere can be considered to consist of a number of parallel air layers. Each layer experiences a pressure on it due to the thrust (or weight) of the air column above it. Therefore, as we go up, the height of air column above us decreases and so thrust exerted by the air column also decreases, which results in the decrease of atmospheric pressure with increase in altitude.

(ii) Since the lower air layers get compressed due to the weight (or thrust) of the upper layers, therefore, the density of air layers is more near the earth surface and it decreases as we go higher and higher. The decrease in density with altitude is *not linear*. It is rapid at low altitude (near the sea level) and is slow at higher altitude. Due to decrease in density of air with altitude, the atmospheric pressure also decreases with altitude in a non-linear way.

Fig. 4.22 shows the variation of atmospheric pressure with height above the sea level. At Mount Everest, the atmospheric pressure is only 30% of the atmospheric pressure at sea level.

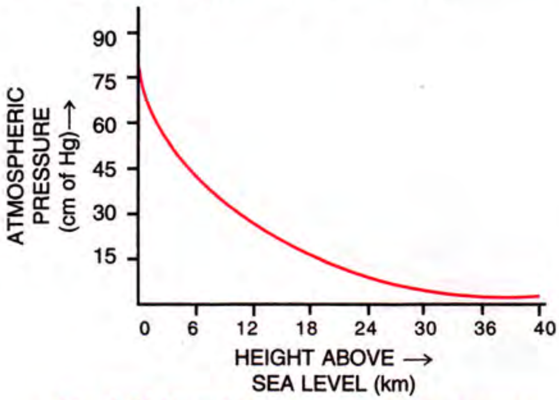


Fig. 4.22 Variation in atmospheric pressure with altitude

Consequences : (1) At high altitudes, since the atmospheric pressure is less, breathing becomes difficult and nose bleeding may occur due to excess of pressure of blood over the atmospheric pressure. Therefore blood pressure patients are not advised to go to hill stations or higher altitudes.

(2) At high altitude, a fountain pen leaks. The reason is that the fountain pen filled with ink contains some air at a pressure equal to the atmospheric pressure on the earth surface. When pen is taken to an altitude, atmospheric pressure at attitude is low so the excess pressure inside the rubber tube forces the ink to leak out.

4.14 WEATHER FORECAST BY THE USE OF BAROMETER

The atmospheric pressure at a place is affected by the change in temperature and the amount of water vapours present in air at that place. The reason is that the density of air changes with the change in temperature and with the change of water vapours present in it. The density of air decreases with the increase in temperature and also with the increase in the amount of moisture present in it (*i.e.*, the density of moist or humid air is less than the density of dry air). Consequently, the atmospheric pressure (or the barometric height) gradually decreases as the temperature or the presence of moisture increases. Thus, the change in the atmospheric pressure helps us to know about the weather in advance. By seeing the barometric height, the weather forecast can be made as follows:

(i) If the barometric height at a place *suddenly falls*, it means that the pressure at that place has suddenly decreased which indicates the *coming of a storm* or *cyclone*.

(ii) If the barometric height *gradually falls,* it indicates that the moisture is increasing *i.e.*, there is a *possibility of rain*.

(iii) A *gradual increase* in the barometric height means that the moisture in air is decreasing. This indicates the coming of a *dry weather.*

(iv) A *sudden rise* in the barometric height means the flow of air from that place to other surrounding low pressure areas. This indicates the coming of an *extremely dry weather*.

(v) If there is *no abrupt change* in barometric height, it indicates that the atmospheric pressure is normal *i.e.*, the weather will remain unchanged.

4.15 ALTIMETER

An altimeter is an aneroid barometer, but it is used in aircraft to measure its altitude. Since atmospheric pressure decreases with the increase in height above the sea level, therefore a barometer which measures the atmospheric pressure, can be used to determine the altitude of a place above the sea level. Its scale is calibrated in terms of height of ascent *with height increasing towards left because the atmospheric pressure decreases with increase of height above the sea level.*

EXAMPLES

1. 'The atmospheric pressure at a place is 75 cm of Hg'. What does it mean ? Express it in N m^{-2}.
Use : density of Hg = 13·6 g cm^{-3}, g = 9·8 m s^{-2}.

The atmospheric pressure at a place is 75 cm of Hg. It means that the atmospheric pressure at that place is equal to the pressure due to mercury column of height 75 cm.

Given : h = 75 cm = 0·75 m, g = 9·8 m s^{-2},
ρ = 13·6 g cm^{-3} = 13·6 × 10^3 kg m^{-3}.

Atmospheric pressure $P = h\rho g$
$= 0{\cdot}75 \times (13{\cdot}6 \times 10^3) \times 9{\cdot}8$
$= \mathbf{9{\cdot}996 \times 10^4}$ **N m^{-2}.**

2. The upper blood pressure of a patient is 160 cm of Hg whereas the normal blood pressure should be 120 cm of Hg. Calculate the extra pressure generated by the heart in S.I. unit. Take density of Hg = 13600 kg m^{-3} and g = 9·8 m s^{-2}.

Given, ρ = 13600 kg m^{-3}, g = 9·8 m s^{-2}

Extra pressure = 160 – 120 = 40 cm = 0·4 m of Hg

From relation $P = h\rho g$

Extra pressure P = 0·4 × 13600 × 9·8
= **5·3312 × 10^4 Pa.**

3. (a) What length of water column is equivalent to 0·76 m of mercury column ? State the assumption made in your calculation.
(b) Can water be used as barometric liquid ? Give a reason.

(a) Given : height of mercury column h_1 = 0·76 m

Let h_2 be the height of water column which will produce same pressure as height h_1 (= 0·76 m) of mercury column.

Then $h_1\rho_1 g = h_2\rho_2 g$

$\therefore \quad h_2 = \dfrac{h_1\rho_1}{\rho_2} = 0{\cdot}76 \times 13{\cdot}6 = \mathbf{10{\cdot}34\ m.}$

Assumption : The density of mercury is 13·6 times the density of water *i.e.,* $\rho_1 = 13{\cdot}6\ \rho_2$

(b) Water cannot be used as the barometric liquid because it will then require the barometer tube of length more than 10·34 m which will be highly inconvenient.

4. A mercury barometer reads 75 cm. Now 3 cm^3 of atmospheric air is introduced into the tube. The mercury falls to a height of 65 cm and the length of air column above the mercury is found to be 15 cm. Calculate the cross sectional area of the barometer tube.

Initial volume of air V_1 = 3 cm^3 at a pressure P_1 = atmospheric pressure = 75 cm of mercury.

The level of mercury falls to 65 cm because the air in the tube exerts pressure on it. Therefore, pressure of air inside the tube, P_2 = 75 – 65 = 10 cm of Hg.

Given, length of air column = 15 cm. If A cm^2 is the area of cross section of the tube, then volume of the trapped air $V_2 = 15 \times A$ cm^3.

By Boyle's law, $P_1V_1 = P_2V_2$

$75 \times 3 = 10 \times (15 \times A)$

$\therefore \quad A = \dfrac{75 \times 3}{10 \times 15} = \mathbf{1{\cdot}5\ cm^2.}$

EXERCISE 4 (B)

1. What do you understand by atmospheric pressure ?
2. Write the numerical value of the atmospheric pressure on the surface of the earth in pascal.
Ans. 1·013 × 10^5 pascal
3. What physical quantity is measured in torr ? How is it related to the S.I. unit of the quantity ?
Ans. Atmospheric pressure, 1 torr = 133·28 Pa
4. Name the physical quantity which is expressed in the unit 'atm'. State its value in pascal.
5. We do not feel uneasy even under the enormous pressure of atmosphere above as well as around us. Give a reason.
6. Describe an experiment to demonstrate that air exerts pressure.
7. Explain the following :
(i) A balloon collapses when air is removed from it.
(ii) Water does not run out of a dropper unless its rubber bulb is pressed.
(iii) Two holes are made in a sealed tin can to take out oil from it.
8. Why does the liquid rise in a syringe when its piston is pulled up ?
9. How is water drawn up from a well by a water pump ?
10. A bell jar connected to a vacuum pump contains a partially inflated balloon. On creating vacuum inside the bell jar, balloon gets more inflated. How does the pressure change : increase, decrease or remains same, inside the (a) bell jar and (b) balloon ?
Ans. (a) decrease, (b) decrease
11. What is the purpose of a barometer ?
Ans. To measure the atmospheric pressure
12. What is a barometer ? How is a simple barometer constructed ?
13. Explain how is the height of mercury column in

the tube of a simple barometer, a measure of the atmospheric pressure.

14. Illustrate with the help of a labelled diagram of a simple barometer that the atmospheric pressure at a place is 76 cm of Hg.
15. Why is the barometric height used as a unit to express the atmospheric pressure ?
16. What is meant by the statement 'the atmospheric pressure at a place is 76 cm of Hg'? State its value in Pa. **Ans.** $1{\cdot}013 \times 10^5$ Pa
17. How will you show that there is vacuum above the surface of mercury in a barometer ? What name is given to this vacuum ?
18. How is the barometric height of a simple barometer affected if
    (a) its tube is pushed down into the trough of mercury?
    (b) its tube is slightly tilted from vertical ?
    (c) a drop of liquid is inserted inside the tube ?
    Ans. (a) remains unaffected (b) remains unaffected (c) decreases
19. State *two* uses of a barometer.
20. Give *two* reasons for the use of mercury as a barometric liquid.
21. Give *two* reasons why water is not a suitable barometric liquid.
22. Mention *two* demerits of a simple barometer and state how they are removed in a Fortin barometer.
23. Draw a simple labelled diagram of a Fortin barometer and state how it is used to measure the atmospheric pressure.
24. What is an aneroid barometer ? Draw a neat and labelled diagram to explain its construction and working.
25. State *two* advantages of an aneroid barometer over a simple barometer.
26. How is the reading of a barometer affected when it is taken to (i) a mine, and (ii) a hill ? **Ans.** (i) increases (ii) decreases.
27. How does the atmospheric pressure change with altitude ? Draw an approximate graph to show this variation.
28. State *two* factors which affect the atmospheric pressure as we go up.
29. Why does a fountain pen leak at a high altitude ?
30. Why does nose start bleeding on high mountains ?
31. What is an altimeter ? State its principle. How is its scale calibrated ?
32. What do the following indicate in a barometer regarding weather :
    (a) gradual fall in the mercury level,
    (b) sudden fall in the mercury level,
    (c) gradual rise in the mercury level ?

Multiple choice type :

1. The unit torr is related to the barometric height as :
   (a) 1 torr = 1 cm of Hg (b) 1 torr = 0·76 m of Hg
   (c) 1 torr = 1 mm of Hg (d) 1 torr = 1 m of Hg
   Ans. (c) 1 torr = 1 mm of Hg
2. The normal atmospheric pressure is :
   (a) 76 m of Hg (b) 76 cm of Hg
   (c) 76 Pa (d) 76 N m^{-2}
   Ans. (b) 76 cm of Hg
3. The atmospheric pressure at earth surface is P_1 and inside mine is P_2. They are related as :
   (a) $P_1 = P_2$ (b) $P_1 > P_2$
   (c) $P_1 < P_2$ (d) $P_2 = 0$
   Ans. (c) $P_1 < P_2$

Numericals :

1. Convert 1 mm of Hg into pascal. Take density of Hg = $13{\cdot}6 \times 10^3$ kg m^{-3} and $g = 9{\cdot}8$ m s^{-2}. **Ans.** 133·28 Pa
2. At a given place, a mercury barometer records a pressure of 0·70 m of Hg. What would be the height of water column if mercury in barometer is replaced by water ? Take density of mercury to be $13{\cdot}6 \times 10^3$ kg m^{-3}. **Ans.** 9·52 m
3. At sea level, the atmospheric pressure is 76 cm of Hg. If air pressure falls by 10 mm of Hg per 120 m of ascent, what is the height of a hill where the barometer reads 70 cm Hg. State the assumption made by you. **Ans.** 720 m
   Assumption : Atmospheric pressure falls linearly with ascent.
4. At sea level, the atmospheric pressure is $1{\cdot}04 \times 10^5$ Pa. Assuming $g = 10$ m s^{-2} and density of air to be uniform and equal to 1·3 kg m^{-3}, find the height of the atmosphere. **Ans.** 8000 m
5. Assuming the density of air to be 1·295 kg m^{-3}, find the fall in barometric height in mm of Hg at a height of 107 m above the sea level. Take density of mercury = $13{\cdot}6 \times 10^3$ kg m^{-3}. **Ans.** 10 mm of Hg

5 UPTHRUST IN FLUIDS, ARCHIMEDES' PRINCIPLE AND FLOATATION

Syllabus :

Buoyancy, Archimedes' principle, floatation, relationship with density; relative density, determination of relative density of a solid.

Scope : Buoyancy, upthrust (F_B); definition; different cases, F_B > = or < weight W of the body immersed; characteristic properties of upthrust; Archimedes' principle; explanation of cases where bodies with density ρ > = or < the density ρ' of the fluid in which it is immersed. R.D. and Archimedes' principle. Experimental determinations of R.D. of a solid and liquid denser than water. Floatation; principle of floatation; relation between the density of a floating body, density of the liquid in which it is floating and the fraction of volume of the body immersed; ($\rho_1/\rho_2 = V_2/V_1$); apparent weight of floating object; application to ship, submarine, iceberg, balloons, etc. Simple numerical problems involving Archimedes' principle and floatation.

(A) UPTHRUST AND ARCHIMEDES' PRINCIPLE

5.1 BUOYANCY AND UPTHRUST

When a body is partially or wholly immersed in a liquid, an upward force acts on it. This upward force is known as ***upthrust or buoyant force***. It is denoted by the symbol F_B. Thus

The upward force exerted on a body by the fluid in which it is submerged, is called the upthrust or buoyant force.

The property of liquid to exert an upward force on a body immersed in it, is called ***buoyancy.*** This property can be demonstrated by the following experiments.

Exp. 1. Pushing an empty can into water : Take an empty can. Close its mouth with an airtight stopper. Put it in a tub filled with water. It floats with a large portion of it above the surface of water and only a small portion of it below the surface of water.

If we push the can into water, we feel an *upward force* which opposes the push and we find it difficult to push the can further into water. It is also noticed that as the can is pushed more and more into water, more and more force is needed to push the can further into water, *till it is completely immersed.* When the can is fully inside water, a constant force is still needed to keep it stationary in that position. Now if the can is released at this position, it is noticed that the can bounces back to the surface and starts floating again.

Exp. 2. Pushing a cork into water : If a piece of cork is placed on the surface of water in a tub, it floats with nearly $\frac{2}{5}$th of its volume inside water. If the cork is pushed into water and then released, it again comes to the surface of water and floats. If the cork is kept immersed, our fingers experience some upward force. The behaviour of cork is similar to that of the empty can.

Explanation : When the can or cork is put in the tub of water, *two* forces act on it : (i) its weight (*i.e.*, the force due to gravity) W which pulls it downwards, and (ii) the upthrust F_B due to water which pushes the can or cork upwards. It floats in the position when the two forces become equal in magnitude (*i.e.*, $W = F_B$). Now as the can or cork is pushed more and more inside water, the upthrust F_B exerted by water on it increases and becomes maximum ($= F'_B$) when it is completely immersed in water. So when it is released, the upthrust F'_B exerted by water on it being greater than its weight W (or force due to gravity), it rises up. To keep the can or cork immersed, an external downward force ($= F'_B - W$) is needed to balance the net upward force.

Note : *Like liquids, gases also have the property of buoyancy, i.e.,* a body immersed (or placed) in a gas also experiences an upthrust. All objects including ourselves, are also acted upon by a buoyant force due to air, but we do not feel it because it is negligibly small as compared to our own weight. On the other hand, a balloon filled with hydrogen (or any gas less denser than air) rises up because the upthrust (or buoyant force) on balloon due to the surrounding air is more than the weight of balloon filled with the gas.

Condition for a body to float or sink in a fluid : When a body is immersed in a fluid, *two* forces act on the body : (i) the weight W of

the body which acts vertically downwards and (ii) the upthrust F_B which acts vertically upwards. We have noticed that the upthrust depends on the submerged portion of the body. It increases as the submerged portion of body inside the fluid increases and becomes maximum ($= F'_B$) when the body is completely immersed inside the fluid. Fig. 5.1 shows a body held completely immersed in a fluid with *two* forces W and F'_B acting on it.

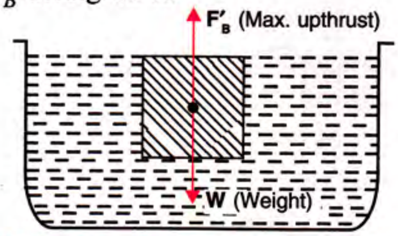


Fig. 5.1 Forces acting on a body held immersed inside a liquid

Depending upon the density of the fluid, the maximum buoyant force F'_B can be greater than, equal to or less than the weight W of the given body. Whether the body will float or sink in a fluid, depends on the relative magnitudes of forces W and F'_B (buoyant force when the body is fully immersed).

(i) If $F'_B > W$ or $F'_B = W$, the body will float (it will not sink). If $F'_B > W$, the body will float partly immersed with only that much part of it inside liquid, the upthrust F_B due to which becomes equal to the weight W of body (*i.e.*, $F_B = W$). But if $F'_B = W$, the body will float with whole of it immersed inside the liquid. Thus *for a floating body, net force acting downwards (i.e., apparent weight) is zero.*

(ii) If $F'_B < W$, the body will sink due to the net force $(W - F'_B)$ acting on the body downwards. If m is the mass of body, it will go down into the liquid with an acceleration a such that $ma = W - F'_B$ or $a = (W - F'_B)/m$. Here we have ignored the viscous force of the liquid.

Unit of upthrust : The upthrust, being a force, is measured in newton (N) or kgf.

5.2 CHARACTERISTIC PROPERTIES OF UPTHRUST

The upthrust has the following *three* characteristic properties :

(i) Larger the volume of body submerged in a fluid, greater is the upthrust.

(ii) For same volume inside the fluid more the density of fluid, greater is the upthrust.

(iii) The upthrust acts on the body in upward direction at the centre of buoyancy i.e., the centre of gravity of the displaced fluid.

(i) Larger the volume of body submerged in a fluid, greater is the upthrust

In the experiment of pushing an empty can or cork into water as described above, it is experienced that the upthrust on the body due to water increases as more and more volume of it is immersed into water, till it is completely immersed.

Similarly, when a bunch of feathers and a pebble of *same mass* are allowed to fall in air, the pebble falls faster than the bunch of feathers. The reason is that upthrust due to air on pebble is less than that on the bunch of feathers because the volume of pebble is less than that of the bunch of feathers of same mass. However in vacuum, both the bunch of feathers and pebble will fall together because there will be no upthrust.

(ii) For same volume inside the fluid more the density of fluid, greater is the upthrust

If we place a piece of cork A into water and another identical cork B into glycerine (or mercury), we notice that the volume of cork B immersed in glycerine (or mercury) is smaller as compared to the volume of cork A immersed in water. The reason is that the density of glycerine (or mercury) is more than that of water. Now if we want to immerse cork B in glycerine to the same extent as cork A in water, then an additional force is needed on cork B, to immerse it to the same level as cork A. This shows that for same volume of a body inside the liquid, a denser liquid exerts a greater upthrust.

(iii) The upthrust acts on the body in upward direction at the centre of buoyancy (i.e., the centre of gravity of the displaced liquid)

For a uniform body completely immersed inside a liquid, the centre of buoyancy coincides with the centre of gravity of the body (Fig. 5.1). But if a body floats in a liquid with its part submerged (Fig. 5.2), the centre of buoyancy B is at the centre of gravity of the displaced liquid (*i.e.*, at the centre of gravity of the immersed part

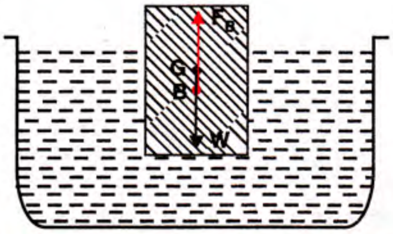


Fig. 5.2 A body floating with part of it submerged

of the body) which lies below the centre of gravity G of the entire body. The weight of the body W acts downwards at G, while upthrust F_B acts upwards at B such that $W = F_B$.

5.3 REASON FOR UPTHRUST

We have read that a liquid contained in a vessel exerts pressure at all points and in all directions. The pressure at a point in liquid is *same* in all directions (upwards, downwards and sideways). *It increases with depth inside the liquid.* When a body, say a block of area of cross section A, is immersed in a liquid (Fig. 5.3), the pressure P_2 exerted upwards on the lower face of block (which is at a greater depth) is *more* than the pressure P_1 exerted downwards on the upper face of block (which is at a lesser depth). Thus there is a difference in pressure ($= P_2 - P_1$) between the lower and upper faces of block. Since force = pressure × area, the difference in pressures due to liquid on the two faces of block causes a net upward force (*i.e.*, upthrust) $= (P_2 - P_1)A$ on the body. However, the thrust on the side walls of body get neutralised as they are equal in magnitude and opposite in directions.

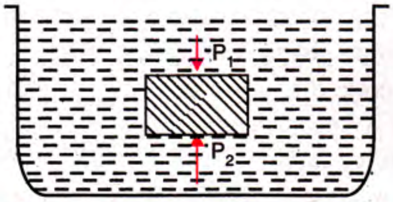


Fig. 5.3 A block immersed in a liquid

Note : If a lamina (thin sheet) is immersed in a liquid, the pressure on its both surfaces will be nearly same, so the liquid will exert negligible upthrust on it, causing it to sink into the liquid due to its own weight.

5.4 UPTHRUST IS EQUAL TO THE WEIGHT OF DISPLACED LIQUID (Mathematical proof)

When a body is immersed in a liquid, upthrust on it due to liquid is equal to the weight of the liquid displaced by the submerged part of the body.

Proof : Consider a cylindrical body $PQRS$ of cross-sectional area A immersed in a liquid of density ρ as shown in Fig. 5.4. Let the upper surface PQ of body be at a depth h_1 while its lower surface RS be at a depth h_2 below the free surface of liquid.

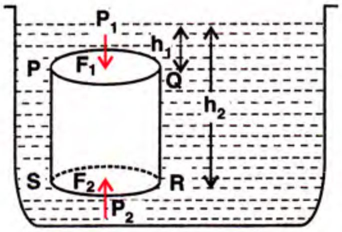


Fig. 5.4 Calculation for upthrust

At depth h_1, pressure on the upper surface PQ

$$P_1 = h_1 \rho g$$

∴ Downward thrust on the upper surface PQ

$$F_1 = \text{pressure} \times \text{area} = h_1 \rho g A \qquad \text{....(i)}$$

At depth h_2, pressure on the lower surface RS

$$P_2 = h_2 \rho g$$

∴ Upward thrust on the lower surface RS

$$F_2 = h_2 \rho g A \qquad \text{....(ii)}$$

The horizontal thrust at various points on the vertical sides of body get balanced because liquid pressure is same at all points at the same depth.

From above eqns. (i) and (ii), it is clear that $F_2 > F_1$ because $h_2 > h_1$ and therefore, the body will experience a net upward force.

Resultant upward thrust (or buoyant force) on the body

$$F_B = F_2 - F_1$$
$$= h_2 \rho g A - h_1 \rho g A$$
$$= A(h_2 - h_1) \rho g$$

But $A (h_2 - h_1) = V$, the volume of the body submerged in liquid.

$$\therefore \quad \boxed{\text{Upthrust } F_B = V \rho g} \qquad \text{....(5.1)}$$

Since a solid when immersed in a liquid, displaces liquid equal to the volume of its submerged part, therefore

$V \rho g$ = Volume of solid immersed × density of liquid × acceleration due to gravity.

or $V\rho g$ = Volume of liquid displaced × density of liquid × acceleration due to gravity.

= mass of liquid displaced × acceleration due to gravity.

= Weight of the liquid displaced by the submerged part of the body.

Hence, **Upthrust = Weight of the liquid displaced by the submerged part of the body.** ...(5.2)

Note : (1) If the body is completely immersed in a liquid, the volume of liquid displaced will be equal to its own volume and upthrust then will be maximum (= F'_B).

(2) Although the above result is derived for a cylindrical body, but it is equally true for a body of any shape and size.

Factors affecting the upthrust

From the above discussion, it is clear that the magnitude of upthrust on a body due to a liquid (or fluid) depends on the following *two* factors :

(i) *volume of the body submerged in liquid (or fluid), and*

(ii) *density of the liquid (or fluid) in which the body is submerged.*

Effect of upthrust : *The effect of upthrust is that the weight of body immersed in a liquid appears to be less than its actual weight.* This can be demonstrated by the following experiment.

Experiment : Lifting of a bucket full of water from a well. Take an empty bucket and tie a long rope to it. If the bucket is immersed in water of a well keeping one end of rope in hand and the bucket is pulled when it is deep inside water, we notice that it is easy to pull the bucket as long as it is inside water, but as soon as it starts coming out of the water surface, it appears to become heavy and now more force is needed to lift it.

This experiment shows that the bucket of water appears lighter when it is immersed in water than its actual weight (in air).

Similarly, when pulling a fish out of water, it appears lighter inside water as compared to when it is out of water.

Similarly, a body weighed by a sensitive spring balance, will weigh slightly less in air than in vacuum due to upthrust of air on the body.

5.5 ARCHIMEDES' PRINCIPLE

When a body is immersed in a liquid, it occupies the space, which was earlier occupied by the liquid *i.e.*, it displaces the liquid. *The volume of liquid displaced by the body is equal to the volume of the submerged part of the body so the body experiences an upthrust equal to the weight of the liquid displaced by it.*

It is the upthrust due to which a body immersed in a liquid appears to be of weight less than its real weight. *The apparent loss in weight is equal to the upthrust on the body.* This is called the Archimedes' principle. Thus

Archimedes' principle states that when a body is immersed partially or completely in a liquid, it experiences an upthrust, which is equal to the weight of the liquid displaced by it.

This principle applies not only to liquids, but it applies equally well to gases also.

5.6 EXPERIMENTAL VERIFICATION OF ARCHIMEDES' PRINCIPLE

Archimedes' principle can be verified by either of the following experiments.

Expt. (1) : Take two cylinders *A* and *B* of the same volume. The cylinder *A* is solid and the cylinder *B* is hollow. Suspend the two cylinders from the left arm of a physical balance keeping the solid cylinder *A* below the hollow cylinder *B*. Then balance the beam by keeping weights on right arm of the balance. In this situation, both cylinders *A* and *B* are in air.

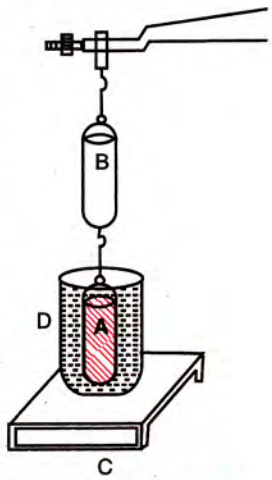


Fig. 5.5 Verification of Archimedes' principle

The solid cylinder *A* is now completely immersed into water contained in a beaker *D* placed on a bench *C* as shown in Fig. 5.5, taking care that the cylinder *A* does not touch the sides and bottom of the beaker. It is observed that the solid cylinder *A* loses weight *i.e.*, the left arm of the balance rises up. Obviously the loss in weight is due to upthrust (or buoyant force) of water on the cylinder *A*.

Now pour water gently in the hollow cylinder *B* till it is completely filled. It is observed that the beam balances again.

Thus, it is clear that *the buoyant force acting on solid cylinder A is equal to the weight of water*

filled in the hollow cylinder B. Since the cylinders A and B both have equal volume, so the weight of water in the hollow cylinder B is just equal to the weight of water displaced by the cylinder A. Hence the buoyant force acting on the cylinder A is equal to the weight of water displaced by it. Thus, it verifies the Archimedes' principle.

Expt. (2) : Take a solid (say, a metallic piece). Suspend it by a thin thread from the hook of a spring balance [Fig. 5.6(a)]. Note its weight.

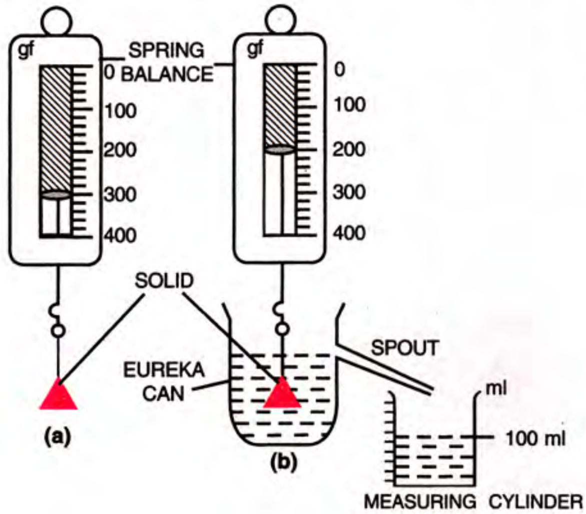


Fig. 5.6 Verification of Archimedes' principle

Now take a *eureka can* and fill it with water up to its spout. Arrange a measuring cylinder below the spout of the eureka can.

Now immerse the solid gently into water of the eureka can. The water displaced by it gets collected in the measuring cylinder [Fig. 5.6 (b)]. When water stops dripping through the spout, note the weight of the solid and the volume of water collected in the measuring cylinder.

In Fig. 5.6, the solid weighs 300 gf in air and 200 gf when it is completely immersed in water. The volume of water collected in the measuring cylinder is 100 ml *i.e.*, 100 cm^3.

$\therefore$ Loss in weight = 300 gf – 200 gf = 100 gf ....(i)

Volume of water displaced = Volume of solid

= 100 cm^3

Since density of water = 1 g cm^{-3}

$\therefore$ Weight of water displaced = 100 gf ....(ii)

From eqns. (i) and (ii)

Weight of water displaced = Upthrust or loss in weight.

Thus the weight of water displaced by solid is equal to the loss in weight of the solid. This verifies Archimedes' principle.

5.7 SOLID BODIES WITH DENSITY (ρ) GREATER THAN DENSITY OF LIQUID (ρ_L) SINK WHILE WITH DENSITY (ρ) LESS THAN DENSITY OF LIQUID (ρ_L) FLOAT

Let a body of volume V and density ρ be immersed completely in a liquid of density ρ_L. The weight of the body acting downwards will be $W = V\rho g$ and the maximum upthrust on the body acting upwards will be $F'_B = V\rho_L g$. Following *three* cases may arise :

(i) If $W > F'_B$ or $V\rho g > V\rho_L g$ or $\rho > \rho_L$, the body will sink due to net force $(W - F'_B)$ acting downwards.

(ii) If $W = F'_B$ or $V\rho g = V\rho_L g$ or $\rho = \rho_L$, the body will float and the net force on the body is zero.

(iii) If $W < F'_B$ or $V\rho g < V\rho_L g$ or $\rho < \rho_L$, the body will float due to net force $(F'_B - W)$ acting upwards and only that much volume v of the body will submerg inside the liquid due to which upthrust F_B $(= v\rho_L g)$ balances the weight W. The net force on the body is zero in this situation also.

Thus a body of density ρ sinks in a liquid of density ρ_L if $\rho > \rho_L$, while it floats if $\rho = \rho_L$ or $\rho < \rho_L$. This can be demonstrated by the following experiments.

Expt. (1) : Take an iron nail and a piece of cork *both of same mass*. First place the iron nail on the surface of water contained in a cup. *The nail sinks*. It implies that the force of gravity (or weight) on iron nail pulling it downwards is greater than the upthrust of water on nail pushing it upwards. Now place the piece of cork on the surface of water. *The cork floats*. It means that upthrust on cork, when fully immersed is more than that on nail because the density of water is more than the density of cork, while the density of water is less than that of iron nail.

Expt. (2) : Take few solid bodies of different materials of known density and place them on the surface of water. It is observed that *if the*

density of the material of the body is equal to or *less than the density of water* (*i.e.*, $\rho = \rho_w$ or $\rho < \rho_w$), *it floats,* implying that the upthrust on body due to its submerged part is equal to its own weight (*i.e.*, $F_B = W$). Different bodies float on water with their different volumes inside water. If $\rho = \rho_w$, the body floats with whole of its volume inside water, while if $\rho < \rho_w$, the body floats with only that much volume inside water by which the upthrust F_B on body balances its weight W. On the other hand, *if the density of the material of body is more than the density of water* (*i.e.*, $\rho > \rho_w$), *the body sinks,* because the upthrust due to water on body is less than its weight (*i.e.*, $F_B < W$).

> Thus the *bodies of density greater than that of liquid, sink in it, while the bodies of average density equal to or smaller than that of liquid, float on it.*

An *empty* tin can (or iron ship) floats on water because its *average density** is less than the density of water.

* The average density of a hollow body is the ratio of mass of the body (= mass of material of body + mass of air enclosed) to its total volume.

EXAMPLES

1. A body weighs 200 gf in air and 190 gf when completely immersed in water. Calculate :
(i) the loss in weight of the body in water,
(ii) the upthrust on the body.

Given : Weight of the body in air = 200 gf
Weight of the body in water = 190 gf

(i) Loss in weight of the body = 200 gf − 190 gf = **10 gf**

(ii) Upthrust on the body = loss in weight = **10 gf.**

2. A small stone of mass m (= 200 g) is held under water in a tall jar and is allowed to fall as shown in Fig. 5.7. The forces acting on stone are also shown.

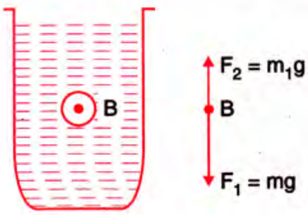


Fig. 5.7

(i) What does F_2 represent ?
(ii) What does m_1 represent ?
(iii) What is the net force acting on stone ?
(iv) What is the acceleration of stone as it falls through water ? Neglect the force due to viscosity. Assume that the volume of stone = 80 cm³, density of water = 1·0 g cm⁻³ and acceleration due to gravity g = 10 m s⁻².

(i) F_2 represents the **upthrust** on stone due to water.

(ii) m_1 represents the **mass of water displaced by stone.**

(iii) Net force acting on stone = $F_1 - F_2$ (downwards).

(iv) Given : $V = 80\text{ cm}^3$, $\rho = 1\text{ g cm}^{-3}$, $g = 10\text{ m s}^{-2}$,

$$m = 200\text{ g} = \frac{200}{1000}\text{ kg} = 0{\cdot}2\text{ kg}$$

∴ weight of stone $F_1 = mg = 0{\cdot}2\text{ kg} \times 10\text{ m s}^{-2} = 2\text{ N}$

Mass of water displaced $m_1 = V\rho = 80 \times 1 = 80\text{ g}$

$$= \frac{80}{1000}\text{ kg} = 0{\cdot}08\text{ kg}$$

upthrust $F_2 = m_1 g = 0{\cdot}08\text{ kg} \times 10\text{ m s}^{-2} = 0{\cdot}8\text{ N}$

Hence net downward force on stone

$$= F_1 - F_2$$
$$= 2 - 0{\cdot}8 = 1{\cdot}2\text{ N}$$

$$\therefore \text{Acceleration} = \frac{\text{Force}}{\text{Mass}} = \frac{1{\cdot}2\text{ N}}{0{\cdot}2\text{ kg}} = \mathbf{6\text{ m s}^{-2}}.$$

3. A piece of iron of density 7·8 × 10³ kg m⁻³ and volume 100 cm³ is completely immersed in water (ρ = 1000 kg m⁻³). Calculate : (i) the weight of iron piece in air, (ii) the upthrust, and (iii) its apparent weight in water. (g = 10 m s⁻²)

Given : Volume of iron piece = 100 cm³
$= 100 \times 10^{-6}\text{ m}^3 = 10^{-4}\text{ m}^3$

(i) Weight of iron piece in air
= Volume × density of iron × g
$= 10^{-4} \times (7{\cdot}8 \times 10^3) \times 10$
= **7·8 N**

(ii) Upthrust = (Volume of water displaced) × density of water × g

But volume of water displaced = volume of iron piece when it is completely immersed = 10^{-4} m^3

∴ Upthrust $= 10^{-4} \times 1000 \times 10 =$ **1 N**

(iii) Apparent weight = True weight – Upthrust

= 7·8 – 1 = **6·8 N.**

4. A metal cube of side 5 cm and density 7·9 g cm^{-3} is suspended by a thread and is immersed completely in a liquid of density 1·1 g cm^{-3}. Find : (a) the weight of cube, (b) the upthrust on cube and (c) the tension in thread.

(a) Given, side of cube = 5 cm

∴ Volume of the cube = 5 × 5 × 5 = 125 cm^3

Mass of the cube = Volume × density

= 125 cm^3 × 7·9 g cm^{-3}

= 987·5 g

∴ Weight of the cube = **987·5 gf (downwards)**

(b) Upthrust on cube= Weight of liquid displaced

= Volume of cube × density of liquid × g

= 125 × 1·1 × g = **137·5 gf (upwards)**

(c) Tension in thread = Net downward force

= Weight of cube – Upthrust on cube

= 987·5 – 137·5 = **850·0 gf.**

5. A solid of density ρ has weight *W*. Show that its apparent weight will be $W[1 - (\rho_L/\rho)]$ when it is completely immersed in a liquid of density ρ_L.

Given, weight of solid = W

∴ Mass of solid = W/g

$$\text{Volume of solid} = \frac{\text{Mass}}{\text{Density}} = \frac{W/g}{\rho}$$

Volume of liquid displaced = Volume of solid

$$= \frac{W/g}{\rho}$$

Upthrust on solid = Volume of liquid displaced × density of liquid × acceleration due to gravity

$$\text{or} \quad \text{upthrust} = \left(\frac{W/g}{\rho}\right) \times \rho_L \times g = \frac{W}{\rho} \times \rho_L$$

∴ Apparent weight = True weight – upthrust

$$= W - \left(\frac{W}{\rho} \times \rho_L\right) = W\left(1 - \frac{\rho_L}{\rho}\right)$$

Hence proved.

EXERCISE 5(A)

1. What do you understand by the term upthrust of a fluid ? Describe an experiment to show its existence.
2. In what direction and at what point does the buoyant force on a body due to a liquid, act ?
   Ans. Upwards, at the centre of buoyancy.
3. What is meant by the term buoyancy ?
4. Define upthrust and state its S.I. unit.
5. What is the cause of upthrust ? At which point it can be considered to act ?
6. Why is a force needed to keep a block of wood inside water ?
   Ans. Upthrust due to water on block when fully submerged is more than its weight.
7. A piece of wood if left under water, comes to the surface. Explain the reason.
8. Describe an experiment to show that a body immersed in a liquid appears lighter than it really is.
9. A metal solid cylinder tied to a thread is hanging from the hook of a spring balance. The cylinder is gradually immersed into water contained in a jar. What changes do you expect in the readings of spring balance ? Explain your answer.
10. Will a body weigh more in air or in vacuum when weighed with a spring balance ? Give a reason for your answer.
11. A body dipped into a liquid experiences an upthrust. State *two* factors on which upthrust on the body depends.
12. How is the upthrust related to the volume of the body submerged in a liquid ?
13. A bunch of feathers and a stone of the same mass are released simultaneously in air. Which will fall faster and why ? How will your observation be different if they are released simultaneously in vacuum ?
14. A body experiences an upthrust F_1 in river water and F_2 in sea water when dipped up to the same level. Which is more F_1 or F_2 ? Give reason.
    Ans. $F_2 > F_1$. **Reason :** Sea water is denser than river water.
15. A small block of wood is held completely immersed in (i) water, (ii) glycerine and then released. In each case, what do you observe ? Explain the difference in your observation in the two cases.
16. A body of volume V and density ρ is kept completely immersed in a liquid of density ρ_L. If g is the acceleration due to gravity, write expressions for the following :
    (i) the weight of the body,
    (ii) the upthrust on the body,
    (iii) the apparent weight of the body in liquid,
    (iv) the loss in weight of the body.
    Ans. (i) $V\rho g$ (ii) $V\rho_L g$ (iii) $V(\rho - \rho_L)g$ (iv) $V\rho_L g$
17. A body held completely immersed inside a liquid experiences two forces : (i) F_1, the force due to gravity and (ii) F_2, the bucyant force. Draw a diagram showing the direction of these forces

acting on the body and state condition when the body will float or sink.

18. Complete the following sentences :

(a) Two balls, one of iron and the other of aluminium experience the same upthrust when dipped completely in water if ....

(b) An empty tin container with its mouth closed has an average density equal to that of a liquid. The container is taken 2 m below the surface of that liquid and is left there. Then the container will ....

(c) A piece of wood is held under water. The upthrust on it will be .... the weight of the wood piece.

Ans. (a) both have equal volume (b) will remains at the same position (c) more than.

19. Prove that the loss in weight of a body when immersed wholly or partially in a liquid is equal to the buoyant force (or upthrust) and this loss is because of the difference in pressure exerted by liquid on the upper and lower surfaces of the submerged part of body.

20. A sphere of iron and another of wood of the same radius are held under water. Compare the upthrust on the two spheres.

[**Hint :** Both have equal volume inside water.]

Ans. 1 : 1

21. A sphere of iron and another of wood, both of same radius are placed on the surface of water. State which of the two will sink ? Give reason to your answer. **Ans.** Sphere of iron will sink.

Reason : $\rho_{iron} > \rho_{water}$, so weight of iron sphere will be more than upthrust due to water on it. But $\rho_{wood} < \rho_{water}$, so sphere of wood will float with its that much volume submerged inside water by which upthrust due to water on it balances its weight.

22. How does the density of material of a body determine whether it will float or sink in water ?

23. A body of density ρ is immersed in a liquid of density ρ_L. State condition when the body will (i) float, (ii) sink, in liquid.

Ans. (i) $\rho <$ or $= \rho_L$ (ii) $\rho > \rho_L$

24. It is easier to lift a heavy stone under water than in air. Explain.

25. State Archimedes' principle.

26. Describe an experiment to verify the Archimedes' principle.

Multiple choice type :

1. A body will experience minimum upthrust when it is completely immersed in :

(a) turpentine (b) water
(c) glycerine (d) mercury.

Ans. (a) turpentine

2. The S.I. unit of upthrust is :

(a) Pa (b) N
(c) kg (d) kg m^2

Ans. (b) N

3. A body of density ρ sinks in a liquid of density ρ_L. The densities ρ and ρ_L are related as :

(a) $\rho = \rho_L$ (b) $\rho < \rho_L$
(c) $\rho > \rho_L$ (d) nothing can be said.

Ans. (c) $\rho > \rho_L$

Numericals :

1. A body of volume 100 cm^3 weighs 5 kgf in air. It is completely immersed in a liquid of density $1{\cdot}8 \times 10^3$ kg m^{-3}. Find : (i) the upthrust due to liquid and (ii) the weight of the body in liquid.

Ans. (i) 0·18 kgf (ii) 4·82 kgf

2. A body weighs 450 gf in air and 310 gf when completely immersed in water. Find :

(i) the volume of the body,
(ii) the loss in weight of the body, and
(iii) the upthrust on the body.

State the assumption made in part (i).

Ans. (i) 140 cm^3 (ii) 140 gf (iii) 140 gf

Assumption : density of water = 1·0 g cm^{-3}.

3. You are provided with a hollow iron ball *A* of volume 15 cm^3 and mass 12 g and a solid iron ball *B* of mass 12 g. Both are placed on the surface of water contained in a large tub. (a) Find upthrust on each ball. (b) Which ball will sink ? Give reason for your answer. (Density of iron = 8·0 g cm^{-3})

Ans. (a) Upthrust on ball *A* = 12 gf and on ball *B* = 1·5 gf. (b) The ball *B* will sink.

Reason : Volume of ball *B* = 12/8·0 = 1·5 cm^3. Upthrust on ball *B* is 1·5 gf which is less than its weight 12 gf, while upthrust on ball *A* will be 15 gf if it is fully submerged, which is greater than its weight 12 gf, so it will float with its that much part submerged for which upthrust becomes equal to its weight (=12 gf).

4. A solid of density 5000 kg m^{-3} weighs 0·5 kgf in air. It is completely immersed in water of density 1000 kg m^{-3}. Calculate the apparent weight of the solid in water. **Ans.** 0·4 kgf

5. Two spheres *A* and *B*, each of volume 100 cm^3 are placed on water (density = 1·0 g cm^{-3}). The sphere *A* is made of wood of density 0·3 g cm^{-3} and the sphere *B* is made of iron of density 8·9 g cm^{-3}.

(a) Find : (i) the weight of each sphere, and (ii) the upthrust on each sphere.

(b) Which sphere will float ? Give reason.

Ans. (a) (i) ***A*** – 30 gf, ***B*** – 890 gf
(ii) ***A*** – 30 gf, ***B*** – 100 gf
(b) The sphere *A* will float

Reason : The density of wood is less than the density of water.

6. The mass of a block made of a certain material is 13·5 kg and its volume is 15×10^{-3} m^3.
   (a) Calculate upthrust on the block if it is held fully immersed in water.
   (b) Will the block float or sink in water when released ? Give reason for your answer.
   (c) What will be the upthrust on block while floating? Take density of water = 1000 kg m^{-3}.

   Ans. (a) 15 kgf. (b) The block will float since upthrust on it when fully immersed in water, is more than its weight. (c) While floating, upthrust = 13·5 kgf.

7. A piece of brass weighs 175 gf in air and 150 gf when fully immersed in water. The density of water is 1·0 g cm^{-3}. (i) What is the volume of the brass piece ? (ii) Why does the brass piece weigh less in water ? **Ans.** (i) 25 cm^3 (ii) due to upthrust.

8. A metal cube of edge 5 cm and density 9·0 g cm^{-3} is suspended by a thread so as to be completely immersed in a liquid of density 1·2 g cm^{-3}. Find the tension in thread. (Take g = 10 m s^{-2})

   [**Hint:** Tension in thread = Apparent weight of the cube in liquid] **Ans.** 9·75 N

9. A block of wood is floating on water with its dimensions 50 cm × 50 cm × 50 cm inside water. Calculate the buoyant force acting on the block. Take g = 9·8 N kg^{-1}. **Ans.** 1225 N

10. A body of mass 3·5 kg displaces 1000 cm^3 of water when fully immersed inside it. Calculate : (i) the volume of body, (ii) the upthrust on body and (iii) the apparent weight of body in water.

    Ans. (i) 1000 cm^3 (ii) 1 kgf (iii) 2·5 kgf

(B) RELATIVE DENSITY AND ITS MEASUREMENT BY ARCHIMEDES' PRINCIPLE

5.8 DENSITY

If *equal volumes* of different substances such as wood, iron, zinc, water, glycerine, mercury etc., are weighed by a physical balance, we find that their *masses are different*. The mass of iron is much more than the mass of an equal volume of wood. This is because the particles of iron are heavier and more closely packed than those of wood. In other words, *iron is denser than wood*. In a similar manner, if we take *equal masses* of cotton and lead (say, one kg each), we notice that their *volumes are different*. The volume of cotton is much larger than the volume of an equal mass of lead. This is because the particles of lead are closely packed, while those of cotton are very loose. In other words, *lead is denser than cotton*. Thus to explain that equal volumes of different substances have different masses or equal masses of different substances have different volumes, we use a term called *density*. It is defined as follows :

The density of a substance is its mass per unit volume. i.e.,

Density of a substance

$$= \frac{\text{Mass of the substance}}{\text{Volume of the substance}} \quad ....(5.3)$$

It is a **scalar** quantity and is represented by the letter ρ (rho) or *d*.

If mass of a substance is *M* and its volume is *V*, its density is

$$\boxed{\rho = \frac{M}{V}} \quad ...... (5.4)$$

Unit of density

$$\text{Unit of density} = \frac{\text{Unit of mass}}{\text{Unit of volume}}$$

In S.I. system, unit of mass is kg and unit of volume is m^3, so S.I. unit of density is kg m^{-3}. In C.G.S. system, unit of mass is g and unit of volume is cm^3, so C.G.S. unit of density is g cm^{-3} (or gram per cubic centimetre).

Relationship between S.I. and C.G.S. units

$$1 \text{ kg m}^{-3} = \frac{1\text{ kg}}{1\text{ m}^3} = \frac{1000\text{ g}}{(100\text{ cm})^3}$$

$$= \frac{1}{1000} \text{ g cm}^{-3}$$

Thus

$$\boxed{\begin{aligned} 1 \text{ kg m}^{-3} &= 10^{-3} \text{ g cm}^{-3} \\ \text{or} \quad 1 \text{ g cm}^{-3} &= 1000 \text{ kg m}^{-3} \end{aligned}} \quad ...... (5.5)$$

Example : The mass of 1 cm^3 of iron is 7·8 g, hence the density of iron is 7·8 g cm^{-3} or 7800 kg m^{-3}. Different substances have different densities.

Effect of temperature on density

Most of the substances expand on heating and contract on cooling, but their mass remains unchanged. Therefore, *density of most of the substances decreases with the increase in temperature and increases with the decrease in temperature.*

Exception : The behaviour of water is however very different due to its uneven expansion. Water when cooled from a high temperature, contracts up to 4°C thereafter it expands below 4°C up to 0°C. Thus the density of water gradually increases when it is cooled up to 4°C, and then starts decreasing when it is cooled further below 4°C up to 0°C. Thus,

> *The density of water is maximum at* 4°C, *equal to* 1 g cm^{-3} *or* 1000 kg m^{-3}.

5.9 RELATIVE DENSITY

$$\left[\text{R.D.} = \frac{\rho_s}{\rho_w} = \frac{m_s}{m_w} \text{ FOR SAME VOLUME}\right]$$

We have read that density of water at 4°C is 1 g cm^{-3} (or 1000 kg m^{-3}). Treating it as a standard, the density of a substance can be compared with the density of water at 4°C and the ratio so obtained is termed as the *relative density* of that substance. Thus,

> ***The relative density (R.D.) of a substance is the ratio of the density of that substance to the density of water at 4°C.***

$$i.e., \text{R.D.} = \frac{\text{Density of substance } (\rho_S)}{\text{Density of water at 4°C } (\rho_W)}$$

$$= \frac{\text{Mass of unit volume of substance}}{\text{Mass of unit volume of water at 4°C}}$$

$$= \frac{\text{Mass of substance } (m_S)}{\text{Mass of an equal volume of water at 4°C } (m_W)} \quad \text{... (5.6)}$$

Thus,

> ***Relative density of a substance is also defined as the ratio of the mass of substance to the mass of an equal volume of water at 4°C.***

Unit of relative density : Since relative density is a pure ratio, *it has no unit.* It is a **scalar quantity.**

Relationship between density and relative density : While calculating the relative density of a substance from its density (or density from its relative density), we note that

(i) In C.G.S. system, density of water at 4°C is 1 g cm^{-3}, so the relative density of a substance is equal to the numerical value of density of that substance. Thus

$$\text{R.D.} = \frac{\text{Density of substance in g cm}^{-3}}{1{\cdot}0 \text{ g cm}^{-3}}$$

or $$\boxed{\text{Density in g cm}^{-3} = \text{R.D.}} \quad \text{....(5.7)}$$

(ii) In S.I. system, density of water at 4°C is 1000 kg m^{-3}, so its relative density is

$$\text{R.D.} = \frac{\text{Density of substance in kg m}^{-3}}{1000 \text{ kg m}^{-3}}$$

or $$\boxed{\text{Density in kg m}^{-3} = (\text{R.D.}) \times 1000} \quad \text{....(5.8)}$$

Examples :

(i) The density of copper is 8·9 g cm^{-3}, its R.D. is 8·9.

(ii) The density of mercury is 13·6 × 10^3 kg m^{-3}, its R.D. is 13·6.

(iii) The R.D. of silver is 10·8, its density in C.G.S. unit is 10·8 g cm^{-3} and in S.I. unit is 10·8 × 10^3 kg m^{-3}.

Difference between density and relative density

Density	*Relative density*
1. Density of a substance is the mass per unit volume of that substance.	1. Relative density of a substance is the ratio of density of that substance to the density of water at 4°C.
2. It is expressed in g cm^{-3} or kg m^{-3}.	2. It has no unit.

Density and R.D. of some common substances

Substance	*Density*		*Relative*
	kg m^{-3}	g cm^{-3}	*density*
Cork	240	0·24	0·24
Wood (pine)	500	0·50	0·50
Petrol	800	0·80	0·80
Turpentine	870	0·87	0·87
Ice	920	0·92	0·92
Olive oil	920	0·92	0·92
Pure water (at 4°C)	1000	1·00	1
Sea water	1025	1·02	1·02
Glycerine	1260	1·26	1·26
Glass	2500	2·5	2·5
Aluminium	2700	2·70	2·70

Iron	7860	7·86	7·86
Copper	8920	8·92	8·92
Silver	10500	10·5	10·5
Mercury	13600	13·6	13·6
Gold	19300	19·3	19·3
Platinum	21500	21·5	21·5

5.10 DETERMINATION OF RELATIVE DENSITY OF A SOLID SUBSTANCE BY ARCHIMEDES' PRINCIPLE

We know that

$$\text{R.D.} = \frac{\text{Mass of the body}}{\text{Mass of water (at 4°C) of volume equal to that of the body}}$$

Using Archimedes' principle, the mass of water of volume equal to that of the body is obtained by finding the mass of water displaced by that body when it is completely immersed in water since a body when immersed in water, displaces water equal to its own volume. Therefore,

$$\text{R.D.} = \frac{\text{Mass of body}}{\text{Mass of water displaced by the body}}$$

$$= \frac{\text{Weight of body}}{\text{Weight of water displaced by the body}}$$

$$= \frac{\text{Weight of body}}{\text{Loss in weight of the body in water (or upthrust)}}$$

or $$\boxed{\text{R.D.} = \frac{\text{Weight of body in air}}{\text{Weight of body in air} - \text{Weight of body in water}}} \quad ...(5.9)$$

Thus, to find relative density of a solid body using Archimedes' principle, we have to weigh the body first in air and then in water. If the weight of body in air is W_1 and in water is W_2, then

$$\boxed{\text{R.D.} = \frac{W_1}{W_1 - W_2}} \quad ...(5.10)$$

Note : Weight and mass are related as weight = mass × acceleration due to gravity (*i.e.*, $W = Mg$). On weighing a body with a physical balance, its mass is expressed in kg or g, while its weight is expressed in kgf or gf.

Now we shall describe the procedure to determine the relative density of a solid in *two* cases : (i) when the solid is *denser* than water and *insoluble in it* and (ii) when the solid is *denser* than water and *soluble in it*.

(i) R.D. of a solid denser than water and insoluble in it

Procedure :

(i) Suspend a piece of the given solid with a thread from hook of the left pan of a physical balance and find its weight W_1.

(ii) Now place a wooden bridge over the left pan of balance and place a beaker nearly two-third filled with water on the bridge. Take care that the bridge and beaker do not touch the pan of balance.

(iii) Immerse the solid completely in water such that it does not touch the walls and bottom of beaker (Fig. 5.8) and find the weight W_2 of solid in water.

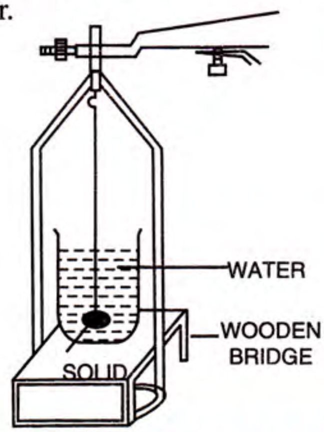


Fig. 5.8 R.D. of a solid denser than water

Observations :

Weight of solid in air $= W_1$ gf

Weight of solid in water $= W_2$ gf

Calculations :

Loss in weight of solid when immersed in water $= (W_1 - W_2)$ gf

$$\text{R.D.} = \frac{\text{Weight of solid in air}}{\text{Loss in weight of solid in water}}$$

or $$\boxed{\text{R.D.} = \frac{W_1}{W_1 - W_2}} \quad ....(5.11)$$

(ii) R.D. of a solid denser than water and soluble in it

Procedure : If solid is soluble in water, instead of water, we take a liquid of known relative density in which solid is insoluble and it sinks in that liquid. Then the process described above is repeated. Now

$$\boxed{\text{R.D.} = \frac{\text{Weight of solid in air}}{\text{Loss in weight of solid in liquid}} \times \text{R.D. of liquid}} \quad ....(5.12)$$

5.11 DETERMINATION OF RELATIVE DENSITY OF A LIQUID BY ARCHIMEDES' PRINCIPLE

By definition, relative density of a liquid is given as :

$$\text{R.D.} = \frac{\text{Weight of a given volume of the liquid}}{\text{Weight of the same volume of water}} \quad ...(5.13)$$

By Archimedes' principle if a solid is immersed in a liquid or water, it displaces the liquid or water equal to its own volume. Therefore the above eqn. (5.13) takes the form :

$$\text{R.D.} = \frac{\text{Weight of liquid displaced by a body}}{\text{Weight of water displaced by the same body}}$$

$$= \frac{\text{Weight of the body in air} - \text{weight of the body in liquid}}{\text{Weight of the body in air} - \text{weight of the body in water}} \quad ...(5.14)$$

Thus to find the relative density of a liquid using Archimedes' principle, we take a body which is heavier than both the given liquid and water and also insoluble in both. The body is first weighed in air, then in liquid and then after washing it with water and drying, it is weighed in water. If the weight of the body in air is W_1 gf, in liquid is W_2 gf and in water is W_3 gf, then from eqn. (5.14)

$$\boxed{\text{R.D. of liquid} = \frac{W_1 - W_2}{W_1 - W_3}} \quad ... (5.15)$$

EXAMPLES

1. Relative density of silver is 10·5. What is the density of silver in S.I. unit ? What assumption do you make in your calculations.

Given, R.D. of silver = 10·5

$$\text{R.D.} = \frac{\text{Density of silver}}{\text{Density of water}}$$

$\therefore$ Density of silver = R.D × density of water

$= \mathbf{10{\cdot}5 \times 10^3\ kg\ m^{-3}}$.

Assumption : Density of water = 10^3 kg m^{-3}.

2. A solid weighs 50 gf in air and 44 gf when completely immersed in water. Calculate :
(i) the upthrust,
(ii) the volume of the solid, and
(iii) the relative density of the solid.

Given, weight of solid in air W_1 = 50 gf and weight of solid in water W_2 = 44 gf.

(i) Upthrust = loss in weight when immersed in water = $W_1 - W_2$ = 50 – 44 = **6 gf**

(ii) Weight of water displaced = upthrust = 6 gf

Since density of water is 1 g cm^{-3}, therefore volume of water displaced = 6 cm^3

But a solid displaces water equal to its own volume, therefore volume of solid = **6 cm^3**.

(iii) $$\text{R.D. of solid} = \frac{\text{Weight of solid in air}}{\text{Weight in air} - \text{Weight in water}}$$

$$= \frac{W_1}{W_1 - W_2} = \frac{50}{50-44} = \frac{50}{6} = \mathbf{8{\cdot}33}$$

3. A solid weighs 30 gf in air and 26 gf when completely immersed in a liquid of relative density 0·8. Find : (i) the volume of solid, and (ii) the relative density of solid.

Given, weight of solid in air W_1 = 30 gf and weight of solid in liquid W_2 = 26 gf., R.D. of liquid = 0·8

$\therefore$ Density of liquid = 0·8 g cm^{-3}

(i) Let V be the volume of solid.

Weight of liquid displaced = Volume of liquid displaced × density of liquid × g

$= V \times 0{\cdot}8 \times g$ dyne

$= V \times 0{\cdot}8$ gf ...(i)

Loss in weight of the solid when immersed in liquid

$= W_1 - W_2 = 30 - 26 = 4$ gf ...(ii)

But the weight of liquid displaced is equal to the loss in weight of solid when immersed in liquid.

$\therefore$ From eqns. (i) and (ii),

$\therefore$ $V \times 0{\cdot}8 = 4$

or $V = \frac{4}{0{\cdot}8} = \mathbf{5\ cm^3}$

(ii) Given, weight of solid = 30 gf

$\therefore$ Mass of solid = 30 g

$$\text{Density of solid} = \frac{\text{Mass}}{\text{Volume}} = \frac{30}{5} = 6\ \text{g cm}^{-3}.$$

Hence relative density of solid = **6**

Alternative method

(i) Volume of solid = Volume of liquid displaced

= mass of liquid displaced / density of liquid

= (30 – 26) / 0·8 = **5 cm^3**.

(ii) R.D. of solid

$$= \frac{\text{Weight of solid in air}}{\text{Weight of solid in air} - \text{weight of solid in liquid}} \times \text{R.D. of liquid}$$

$$= \frac{30}{30-26} \times 0{\cdot}8 = \frac{30}{4} \times 0{\cdot}8 = \mathbf{6}$$

4. A solid body weighs 2·10 N in air. Its relative density is 8·4. How much will the body weigh if placed
(i) in water,
(ii) in a liquid of relative density 1·2 ?

(i) Given : Weight of the body in air W_1 = 2·10 N, R.D. of body = 8·4, weight of body in water W_2 = ?

$$\text{R.D.} = \frac{W_1}{W_1 - W_2} \quad \therefore \quad 8\cdot4 = \frac{2\cdot1}{2\cdot1 - W_2}$$

or $8\cdot4\,(2\cdot1 - W_2) = 2\cdot1$

or $W_2 = \frac{2\cdot1 \times 7\cdot4}{8\cdot4} = \mathbf{1\cdot85\ N}$

Thus weight of body in water = **1·85 N**

(ii) Upthrust due to water $= W_1 - W_2 = 2\cdot10 - 1\cdot85 = 0\cdot25$ N

Upthrust due to liquid
= Upthrust due to water × R.D. of liquid
= 0·25 × 1·2 = 0·30 N

∴ Weight of body in liquid = Weight of body in air – Upthrust due to liquid
= 2·10 – 0·30 = **1·8 N.**

Alternative method :

Let weight of body in liquid be x N. Then R.D.

$$= \frac{\text{Weight of body in air}}{\text{Weight of body in air} - \text{Weight of body in liquid}} \times \text{R.D. of liquid}$$

or $8\cdot4 = \frac{2\cdot1}{2\cdot1 - x} \times 1\cdot2$

or $4\,(2\cdot1 - x) = 1\cdot2$ or $x = \frac{7\cdot2}{4} = \mathbf{1\cdot8\ N}$

5. A body weighs 82·1 gf in air, 75·5 gf in water and 73·8 gf in a liquid. (a) Find the relative density of the liquid. (b) How much will it weigh if immersed in a liquid of relative density 0·87 ?

(a) Given, weight of the body in air W_1 = 82·1 gf
Weight of the body in liquid = W_2 = 73·8 gf
Weight of the body in water W_3 = 75·5 gf

$$\text{R.D. of liquid} = \frac{W_1 - W_2}{W_1 - W_3} = \frac{82\cdot1 - 73\cdot8}{82\cdot1 - 75\cdot5} = \frac{8\cdot3}{6\cdot6} = \mathbf{1\cdot26}$$

(b) Given, R.D. of liquid = 0·87, W_1 = 82·1 gf, W_2 = ?, W_3 = 75·5 gf

From relation $\text{R.D.} = \frac{W_1 - W_2}{W_1 - W_3}$

$$0\cdot87 = \frac{82\cdot1 - W_2}{82\cdot1 - 75\cdot5}$$

or $82\cdot1 - W_2 = 0\cdot87 \times 6\cdot6 = 5\cdot742$

∴ $W_2 = 82\cdot1 - 5\cdot742 = 76\cdot358$
$= \mathbf{76\cdot4\ gf}$

EXERCISE 5(B)

1. Define the term density.
2. What are the units of density in (i) C.G.S. and (ii) S.I. system. **Ans.** (i) g cm^{-3} (ii) kg m^{-3}
3. Express the relationship between the C.G.S. and S.I. units of density.
Ans. 1 g cm^{-3} = 1000 kg m^{-3}
4. 'The density of iron is 7800 kg m^{-3}'. What do you understand by this statement ?
5. Write the density of water at 4°C in S.I. unit.
Ans. 1000 kg m^{-3}
6. How are the (i) mass, (ii) volume, and (iii) density of a metallic piece affected, if at all, with increase in temperature ?
Ans. (i) unchanged, (ii) increases, (iii) decreases.
7. Water is heated from 0°C to 10°C. How does the density of water change with temperature ?
Ans. On heating from 0°C, the density of water increases up to 4°C and then decreases beyond 4°C.
8. Complete the following sentences :
(i) Mass = ... × density
(ii) S.I. unit of density is ....
(iii) Density of water is ... kg m^{-3}.
(iv) Density in kg m^{-3} = ... × density in g cm^{-3}
Ans. (i) volume, (ii) kg m^{-3}, (iii) 1000, (iv) 1000
9. What do you understand by the term relative density of a substance ?
10. What is the unit of relative density ?
Ans. No unit
11. Differentiate between density and relative density of a substance.
12. With the use of Archimedes' principle, state how you will find relative density of a solid denser than water and insoluble in it. How will you modify your experiment if the solid is soluble in water ?
13. A body weighs W gf in air and W_1 gf when it is completely immersed in water. Find : (i) volume

of the body, (ii) upthrust on the body, (iii) relative density of material of the body.

Ans. (i) $(W - W_1)$ cm^3 (ii) $(W - W_1)$ gf (iii) $\frac{W}{W - W_1}$

14. Describe an experiment, using Archimedes' principle, to find relative density of a liquid.

15. A body weighs W_1 gf in air and when immersed in a liquid it weighs W_2 gf, while it weighs W_3 gf on immersing it in water. Find : (i) volume of the body (ii) upthrust due to liquid (iii) relative density of the solid and (iv) relative density of the liquid.

Ans. (i) $(W_1 - W_3)$ cm^3, (ii) $(W_1 - W_2)$ gf, (iii) $\frac{W_1}{W_1 - W_3}$ (iv) $\frac{W_1 - W_2}{W_1 - W_3}$

Multiple choice type :

1. Relative density of a substance is expressed by comparing the density of that substance with the density of :
   (a) air (b) mercury
   (c) water (d) iron.

   Ans. (c) water

2. The unit of relative density is :
   (a) g cm^{-3} (b) kg m^{-3}
   (c) m^3 kg^{-1} (d) no unit.

   Ans. (d) no unit

3. The density of water is :
   (a) 1000 g cm^{-3} (b) 1 kg m^{-3}
   (c) 1 g cm^{-3} (d) none of these.

   Ans. (c) 1 g cm^{-3}

Numericals :

1. The density of copper is 8·83 g cm^{-3}. Express it in kg m^{-3}. **Ans.** 8830 kg m^{-3}

2. The relative density of mercury is 13·6. State its density in (i) C.G.S. unit, (ii) S.I. unit.
   Ans. (i) 13·6 g cm^{-3} (ii) 13·6 × 10^3 kg m^{-3}

3. The density of iron is 7·8 × 10^3 kg m^{-3}. What is its relative density ? **Ans.** 7·8

4. The relative density of silver is 10·8. Find its density. **Ans.** 10·8 × 10^3 kg m^{-3}

5. Calculate the mass of a body whose volume is 2 m^3 and relative density is 0·52. **Ans.** 1040 kg

6. Calculate the mass of air in a room of dimensions 4·5 m × 3·5 m × 2·5 m if the density of air at N.T.P. is 1·3 kg m^{-3}. **Ans.** 51·19 kg

7. A piece of stone of mass 113 g sinks to the bottom in water contained in a measuring cylinder and water level in cylinder rises from 30 ml to 40 ml. Calculate R.D. of stone. **Ans.** 11·3

8. A body of volume 100 cm^3 weighs 1 kgf in air. Find : (i) its weight in water and (ii) its relative density.
   Ans. (i) 900 gf, (ii) 10

9. A body of mass 70 kg, when completely immersed in water, displaces 20,000 cm^3 of water. Find : (i) the weight of body in water and (ii) the relative density of material of body.
   Ans. (i) 50 kgf, (ii) 3·5

10. A solid weighs 120 gf in air and and 105 gf when it is completely immersed in water. Calculate the relative density of solid.
    Ans. 8

11. A solid weighs 32 gf in air and 28·8 gf in water. Find : (i) the volume of solid, (ii) R.D. of solid, and (iii) the weight of solid in a liquid of density 0·9 g cm^{-3}.
    Ans. (i) 3·2 cm^3, (ii) 10, (iii) 29·12 gf

12. A body weighs 20 gf in air and 18·0 gf in water. Calculate relative density of the material of body.
    Ans. 10

13. A solid weighs 1·5 kgf in air and 0·9 kgf in a liquid of density 1·2 × 10^3 kg m^{-3}. Calculate R.D. of solid. **Ans.** 3·0

14. A jeweller claims that he makes ornament of pure gold of relative density 19·3. He sells a bangle weighing 25·25 gf to a person. The clever customer weighs the bangle when immersed in water and finds that it weighs 23·075 gf in water. With the help of suitable calculations find out whether the ornament is made of pure gold or not.

    [**Hint :** Calculate R.D. of material of bangle which comes out to be 11·6].

    Ans. Gold is not pure.

15. A piece of iron weighs 44·5 gf in air. If the density of iron is 8·9 × 10^3 kg m^{-3}, find the weight of iron piece when immersed in water.
    Ans. 39·5 gm

16. A piece of stone of mass 15·1 g is first immersed in a liquid and it weighs 10·9 gf. Then on immersing the piece of stone in water, it weighs 9·7 gf. Calculate :
    (a) the weight of the piece of stone in air,
    (b) the volume of the piece of stone,
    (c) the relative density of stone,
    (d) the relative density of the liquid.

    Ans. (a) 15·1 gf, (b) 5·4 cm^3, (c) 2·8, (d) 0·78

(C) FLOATATION

5.12 PRINCIPLE OF FLOATATION

We have read that when a body is immersed in a liquid, the following *two* forces act on it :

(i) The weight W of body acting vertically downwards, through the centre of gravity G of the body. This force has a tendency to sink the body.

(ii) The upthrust F_B of the liquid acting vertically upwards, *through the centre of buoyancy B i.e., the centre of gravity of the displaced liquid*. The upthrust (or buoyant force) is equal in magnitude to the weight of the liquid displaced. This force has a tendency to make the body float.

Fig. 5.9 shows the two forces W and F_B acting on a body floating on a liquid.

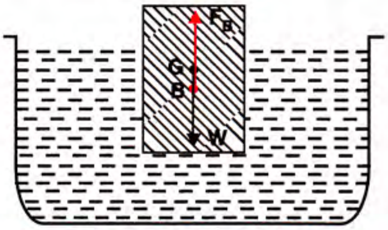


Fig. 5.9 Two forces acting on a floating body

In magnitude,

W = volume of body × density of body × g ..(5.16)

and F_B = volume of submerged part of body × density of liquid × g ...(5.17)

Obviously, the upthrust F_B is maximum (=F'_B) when the body is completely immersed inside the liquid.

Depending upon whether the maximum upthrust F'_B is less than, equal to or greater than the weight W, the body will either sink or float in liquid. So we consider the following *three* cases when (i) $W > F'_B$ (ii) $W = F'_B$ and (iii) $W < F'_B$.

Case (i) : *When $W > F'_B$ i.e., the weight of the body is greater than the weight of the displaced liquid.* In this case, the body will sink as shown in Fig. 5.10. The apparent weight of the body (*i.e.*, the weight of body inside liquid) as measured by a spring balance if it is attached with the body will be ($W - F'_B$) acting vertically downwards. This is the case when the density ρ of solid is greater than the density ρ_L of liquid (*i.e.*, $\rho > \rho_L$).

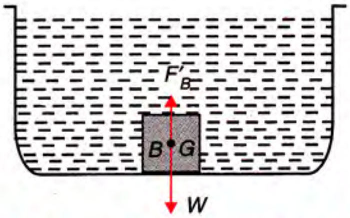


Fig. 5.10 The body sinks when $W > F'_B$

Case (ii) : *When $W = F'_B$ i.e., the weight of the body is equal to the weight of the displaced liquid.* In this case, the body will float just below the surface of liquid as shown in Fig. 5.11. The *apparent weight of body will be zero.* The density ρ of such a body is equal to the density ρ_L of liquid (*i.e.*, $\rho = \rho_L$).

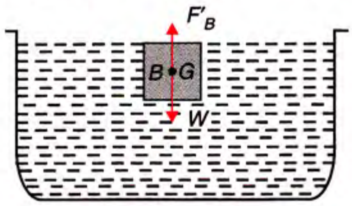


Fig. 5.11 The body floats when $W = F'_B$

Case (iii) : *When $W < F'_B$ i.e., the weight of the body is less than the weight of the liquid displaced by it when it is held completely immersed in the liquid.* In this case, the body floats partially above and partially below the surface of liquid as shown in Fig. 5.12. *Only that much portion of the body gets submerged by which the weight of displaced liquid becomes equal to the weight of the body.* In this situation,

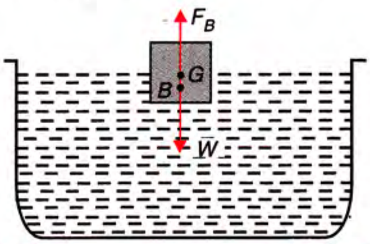


Fig. 5.12 The body floats partially inside the liquid when $W < F'_B$ on complete immersion

while floating, weight W acts at the centre of gravity G of the body, while upthrust F_B acts at the centre of buoyancy B which is vertically below G, and weight W is equal to upthrust F_B *only due to the submerged part of the body*. Thus, the apparent weight of the body will be zero in this case also. The density ρ of such a body is less than the density ρ_L of liquid (*i.e.*, $\rho < \rho_L$).

From the above discussion, we find that for a floating body,

Weight of body
= Weight of liquid displaced by the submerged part of body.

or $W = F_B$ .....(5.18)

$\therefore$ Apparent weight of a floating body = 0 (zero)

This is the *principle of floatation*. Thus,

According to the principle of floatation, the weight of a floating body is equal to the weight of the liquid displaced by its submerged part.

5.13 RELATION BETWEEN VOLUME OF SUBMERGED PART OF A FLOATING BODY, THE DENSITIES OF LIQUID AND THE BODY $\left(\frac{v}{V} = \frac{\rho_s}{\rho_L}\right)$

Let V be the volume of a body of density ρ_s. Let the body be floating with its volume v immersed inside a liquid of density ρ_L. Then

Weight of the body W = Volume of body × density of body × g

$= V\rho_s g$

Weight of liquid displaced by the body or upthrust

F_B = Volume of displaced liquid × density of liquid × $g = v\rho_L g$

For floatation, $W = F_B$

i.e., $V\rho_s g = v\rho_L g$

or $$\boxed{\frac{v}{V} = \frac{\rho_s}{\rho_L}} \quad .....(5.19)$$

Thus,

$$\frac{\text{Volume of immersed part of body}}{\text{Total volume of body}} = \frac{\text{Density of body}}{\text{Density of liquid}}$$

Examples : (1) A cork of density $\rho_s = \frac{3}{4}$ g cm^{-3} while floating in water will have its $\frac{3}{4}$th part immersed inside water (ρ_L = 1 g cm^{-3}) and $\frac{1}{4}$th part outside the surface of water.

(2) A cube of ice (density ρ_s = 0·9 g cm^{-3}) will have 90% of its volume immersed in water (density ρ_L = 1 g cm^{-3}) while floating and only 10% outside the surface of water.

5.14 APPLICATIONS OF THE PRINCIPLE OF FLOATATION

(i) *Floatation of iron ship*

An iron nail sinks in water while a ship floats : If we place an iron nail on the surface of water, it sinks. This is because the density of iron is greater than that of water, so the weight of nail is more than the upthrust of water on it.

On the other hand, ships are also made of iron, but they do not sink. This is because the ship is hollow and the empty space in it contains air which makes its volume large and *average density less than that of water*. Therefore, even with a small portion of ship submerged in water, the weight of water displaced by the submerged part of ship becomes equal to the total weight of ship and therefore it floats.

A loaded ship is submerged more while an unloaded ship is less submerged : When cargo is loaded on a sailing ship, its weight increases, so it sinks further to displace more water till the weight of water displaced by its submerged part becomes equal to the weight of loaded ship. If cargo is unloaded, the ship will rise in water till the weight of water displaced balances the weight of unloaded ship.

A ship begins to submerge more as it sails from sea water to river water : The water of river is of low density than that of a sea and the density of water of different sea is also different. Therefore, when a ship sails from a sea of water of higher density to a sea of water of lower density (or from sea water to river water), it sinks further. The reason is that according to the law of floatation, to balance the weight of ship,

a greater volume of water is required to be displaced in water of lower density in river (or sea).

Plimsoll line : Each ship has a white line painted on its side, known as the *Plimsoll line*. This line indicates the safe limit for loading the ship in water of density 10^3 kg m^{-3}. A ship is not allowed to be loaded further when its Plimsoll line starts touching the water level, so that when it sails in sea water of density more than 10^3 kg m^{-3}, only the part of it below the plimsoll line remains submerged in water.

An unloaded ship is filled with sand at its bottom : An unloaded ship floats with its very small volume inside water. As a result, its centre of gravity is higher and its equilibrium is *unstable*. There is a danger that it may get blown over on its side by strong winds. Therefore, an unloaded ship is filled with sand (or stones), called *ballast*, at its bottom. This lowers its centre of gravity to make its equilibrium stable.

(ii) *Floatation of human body*

The average density of human body depends on the proportion of its constituents like bone, blood, muscles and fat in him as each constituent has different density. Further, it also depends on the amount of air in his lungs at that time. The average density of body with empty lungs is 1·07 g cm^{-3}, while with lungs filled with air is 1·00 g cm^{-3}. A good swimmer can float on water, like a floating object, with his lungs filled with air and nose and mouth projecting just above the water surface. The weight of water displaced by him is then nearly equal to his own weight. Thus, he can swim with a very little effort.

It is easier for a man to swim in sea water than in fresh (or river) water : The reason is that due to presence of minerals (salt etc.), the density of sea water (= 1·026 g cm^{-3}) is more than the density of fresh (or river) water (= 1·0 g cm^{-3}). Therefore, with a smaller portion of the body submerged in sea water, the weight of water displaced becomes equal to the total weight of the body, while to displace the same weight of fresh (or river) water, a large portion of his body will have to be submerged in water. So it becomes difficult to swim in river water.

In the Dead Sea, the density of water is much more (= 1·16 g cm^{-3}), therefore, a man can easily swim in Dead Sea with a small portion submerged inside water so as to balance his weight.

(iii) *Floatation of submarines*

A submarine is a fish shaped water-tight boat provided with several ballast (or *floatation*) tanks in its front and rear parts. Fig. 5.13 shows the portion of a submarine to explain its floatation. It is provided with periscopes so that the diver could see above the water surface even when the submarine is well inside the water.

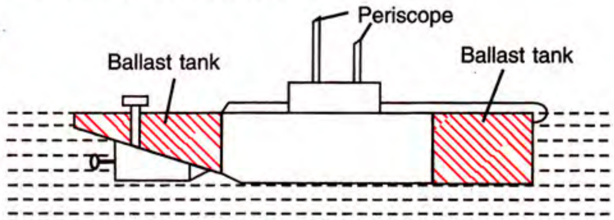


Fig. 5.13 Submarine

A submarine can be made to dive into the water or rise up to the surface of water as and when desired. If a submarine is to dive, its ballast tanks are filled with water so that the average density of submarine becomes greater than the density of sea water and the submarine dives into the water. If submarine is to rise, water from the ballast tanks is forced out into the sea by allowing the compressed air to enter the tank. This makes the average density of submarine less than that of sea water. As a result, the weight of water displaced by its partially small submerged part becomes equal to the weight of submarine and hence it rises up to the surface of water.

(iv) *Floatation of iceberg*

The density of ice is less than the density of water. The density of ice is 0·917 g cm^{-3} and that of water is 1 g cm^{-3}. Therefore, huge masses of ice known as *icebergs* are able to float on water with their major part inside the water surface and only a small portion above the water surface.

Volume of iceberg above the water surface while floating : If the total volume of an iceberg is V and the volume of iceberg submerged is v, then by the principle of floatation,

Weight of water displaced by the submerged part of iceberg = Total weight of iceberg

or $$v \times \rho_{water} \times g = V \times \rho_{ice} \times g$$

or $$\boxed{\frac{v}{V} = \frac{\rho_{ice}}{\rho_{water}}} \qquad \text{....(5.20)}$$

Examples : (1) An iceberg ($\rho_{ice} = 0{\cdot}917$ g cm^{-3}) floats on water (ρ_{water} = 1·0 cm^{-3}) with volume $v = 0{\cdot}917\ V$ *i.e.* 91·7% of its total volume below the water surface or only 8·3% of its volume above the water surface as shown in Fig. 5.14.

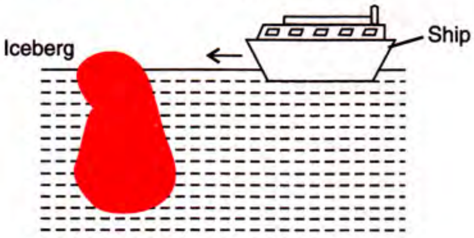


Fig. 5.14 Floating iceberg

(2) An iceberg ($\rho_{ice} = 0{\cdot}917$ g cm^{-3}) floats on sea water ($\rho_{water} = 1{\cdot}026$ g cm^{-3}) with volume $v = \frac{0{\cdot}917}{1{\cdot}026} V = 0{\cdot}893\ V$ *i.e.*, 89·3% of its total volume submerged inside sea water and only 10·7% above sea water.

Icebergs are dangerous for ships : Icebergs being lighter than water, float on water with their major part (nearly 90%) inside water and only a small part (≈10%) outside water. Since portion of iceberg inside the water surface depends upon the density of sea water, therefore for the driver of ship, it becomes difficult to estimate the size of iceberg. Thus an iceberg is very dangerous for the ship as it may collide with the ship and cause damage.

No change in level of water on melting a floating piece of ice : When a floating piece of ice melts into water, it contracts by the volume equal to the volume of ice piece above the water surface while floating on it. Hence the level of water does not change when the ice floating on it melts.

(v) *Floatation of fish*

Many species of fish have an organ called a *swim bladder.* It acts like the ballast (or floatation) tank of a submarine. When a fish has to rise up in water, it diffuses gas from its fluid into the bladder, so its volume increases and its average density decreases. This increases the volume of water displaced by the fish and so the upthrust on fish increases due to which it rises up. When the fish has to come down, it empties its bladder to the required extent, so its volume decreases and density increases. Hence upthrust on fish decreases and it sinks in water.

(vi) *Rising of balloons*

When a light gas like hydrogen or helium (density much less than that of air) is filled in a balloon, the weight of air displaced by the inflated balloon (*i.e.*, upthrust) becomes more than the weight of the gas filled balloon and it rises up.

The balloon does not rise indefinitely. The reason is that the density of air decreases with altitude. Therefore as the balloon gradually goes up, the weight of the displaced air (*i.e.*, upthrust) decreases. It keeps on rising as long as the upthrust on it exceeds its weight. When upthrust becomes equal to its weight, it stops rising further.

EXAMPLES

1. A block of wood of volume 25 cm^3 floats on water with 20 cm^3 of its volume immersed. Calculate : (i) the density, and (ii) the weight of block of wood.

Given : Volume of block $V = 25$ cm^3,
Volume immersed in water $v = 20$ cm^3

(i) If density of wood is ρ g cm^{-3}, then by principle of floatation.

Weight of block of wood = Weight of water displaced by the immersed part of block.

$V\rho g = v \times 1 \times g$ (since density of water = 1 g cm^{-3})

$\therefore\ \rho = \frac{v}{V} = \frac{20}{25} = \mathbf{0{\cdot}8\ g\ cm^{-3}}$

(ii) Weight of block of wood = $V\rho g$
$= 25 \times 0{\cdot}8 \times g = 20\ g$ dyne
$=$ **20 gf .**

2. A block of iron floats on mercury. Find the fraction of volume which remains immersed in mercury. (Densities of iron and mercury are $7{\cdot}8$ g cm^{-3} and $13{\cdot}6$ g cm^{-3} respectively)

Let V be the volume of iron block and v be its volume immersed in mercury. For floatation,

Weight of block = Weight of mercury displaced by the immersed portion of block.

i.e., $V \times 7{\cdot}8 \times g = v \times 13{\cdot}6 \times g$

or $\dfrac{v}{V} = \dfrac{7.8}{13.6} = \mathbf{0{\cdot}574}$

or $v = 0{\cdot}574\ V$

The fraction **0·574 of total volume** will remain immersed in mercury.

3. An iceberg floats on fresh water with a part of it outside the water surface. Calculate the fraction of the volume of the iceberg which is below the water surface.

Given : density of ice = 917 kg m^{-3}, density of fresh water = 1000 kg m^{-3}.

By the principle of floatation,

$$\frac{\text{Volume of iceberg immersed}}{\text{Total volume of iceberg}} = \frac{\text{Density of ice}}{\text{Density of fresh water}}$$

$$= \frac{917}{1000} = \mathbf{0{\cdot}917}$$

Thus $0{\cdot}917^{\text{th}}$ part of volume of iceberg will remain below the water surface.

4. A block of wood floats on water with $\frac{2}{5}$th of its volume above the water surface. Calculate the density of wood.

Let the volume of block be V and density of wood be ρ. Volume of block above the surface of water $= \dfrac{2}{5}\ V.$

$\therefore$ Volume of block immersed $v = V - \dfrac{2}{5}\ V = \dfrac{3}{5}\ V$

By the principle of floatation,

Weight of the block = Weight of water displaced by the immersed part of block

i.e., $V \times \rho \times g = \dfrac{3}{5}\ V \times 1 \times g$

$$\rho = \frac{3}{5} = \mathbf{0{\cdot}6\ g\ cm^{-3}}.$$

(Here the density of water is taken as 1 g cm^{-3})

5. A piece of wood of volume 200 cm^3 and density $0{\cdot}84$ g cm^{-3} floats in a liquid of density $1{\cdot}05$ g cm^{-3}.

(i) What volume of wood will remain above the surface of liquid ?

(ii) What force must be exerted on wood to keep it totally submerged ?

Given, $V = 200$ cm^3, $\rho_s = 0{\cdot}84$ g cm^{-3}, $\rho_L = 1{\cdot}05$ g cm^{-3}

(i) Let V' cm^3 be the volume of wood which remains above the surface of liquid. Then submerged volume of wood $v = V - V' = (200 - V')$ cm^3 and by the principle of floatation,

Weight of wood piece

= Upthrust due to submerged part of wood

$$200 \times 0{\cdot}84 \times g = (200 - V') \times 1{\cdot}05 \times g$$

$$\therefore \quad V' = \frac{200 \times (1{\cdot}05 - 0{\cdot}84)}{1{\cdot}05}$$

$$= \frac{200 \times 0{\cdot}21}{1{\cdot}05} = \mathbf{40\ cm^3}$$

(ii) When wood piece is totally submerged, then

Upthrust $= V \times \rho_L \times g = 200 \times 1{\cdot}05 \times g$
$= 210$ gf (upwards)

Weight of wood piece $= V \times \rho_s \times g = 200 \times 0{\cdot}84 \times g$
$= 168$ gf (downwards)

$\therefore$ Force to be exerted to keep the wood totally submerged

= Upthrust – Weight of wood piece

= 210 – 168 = **42 gf.**

6. The volume of a balloon is 1000 m^3. It is filled with helium of density $0{\cdot}18$ kg m^{-3}. What maximum load can it lift ? Density of air is $1{\cdot}29$ kg m^{-3}.

Given, volume of balloon $V = 1000$ m^3,

density of helium $\rho = 0{\cdot}18$ kg m^{-3},

density of air $= 1{\cdot}29$ kg m^{-3}

Weight of helium filled balloon

$= V \times \rho \times g = 1000 \times 0{\cdot}18 \times g$

$= 180\ g$ N $= 180$ kgf

Weight of air displaced = upthrust

$= V \times$ density of air $\times g$

$= 1000 \times 1{\cdot}29 \times g$

$= 1290\ g$ N $= 1290$ kgf

Resultant upward force on balloon

= upthrust – weight of balloon

= 1290 – 180 = 1110 kgf.

So it can lift a maximum load of **1110 kgf.**

EXERCISE 5 (C)

1. State the principle of floatation.
2. A body is held immersed in a liquid. (i) Name the *two* forces acting on body and draw a diagram to show these forces. (ii) State how do the magnitudes of two forces mentioned in part (i) determine whether the body will float or sink in liquid when it is released. (iii) What is the net force on body if it (a) sinks, (b) floats ?
3. When a piece of wood is suspended from the hook of a spring balance, it reads 70 gf. The wood is now lowered into water. What reading do you expect on the scale of spring balance ?
   [**Hint :** The piece of wood will float on water and while floating, apparent weight = 0]. **Ans.** Zero
4. A solid iron ball of mass 500 g is dropped in mercury contained in a beaker. (a) Will the ball float or sink ? Give reason. (b) What will be the apparent weight of ball ? Give reason.
   Ans. (a) Float, **Reason:** Density of ball (*i.e.*, iron) is less than the density of mercury. (b) Zero
   Reason : While floating, upthrust = weight.
5. How does the density of a substance determine whether a solid piece of that substance will float or sink in a given liquid ?
   Ans. The body will float if $\rho_s \le \rho_L$ and it will sink if $\rho_s > \rho_L$
6. Explain why an iron nail floats on mercury, but it sinks in water.
   [**Hint :** Density of iron is less than that of mercury, but more than that of water]
7. A body floats in a liquid with a part of it submerged inside liquid. Is the weight of floating body greater than, equal to or less than upthrust ?
   Ans. Equal to
8. A homogeneous block floats on water (a) partly immersed (b) completely immersed. In each case state the position of centre of buoyancy *B* with respect to the centre of gravity *G* of the block.
   Ans. (a) *B* will lie vertically below *G* (b) *B* will coincide *G*
9. Fig. 5.15 shows the same block of wood floating in three different liquids *A*, *B* and *C* of densities ρ_1, ρ_2 and ρ_3 respectively. Which of the liquid has the highest density ? Give reason for your answer.

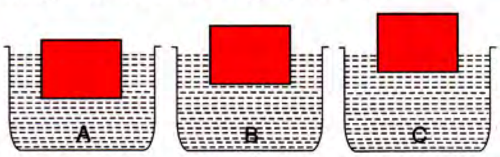


Fig. 5.15

Ans. *C*

Reason : The upthrust on the body by each liquid is same and it is equal to the weight of body. But upthrust = volume submerged × $\rho_L \times g$. For liquid *C*, since volume submerged is least so density ρ_3 must be maximum.

10. Draw a diagram to show the forces acting on a body floating in water with its some part submerged. Name the forces and show their points of application. How is the weight of water displaced by the floating body related to the weight of the body itself ?
11. What is centre of buoyancy ? State its position for a floating body with respect to the centre of gravity of body.
12. A balloon filled with helium gas floats in a big closed jar which is connected to an evacuating pump. What will be your observation, if air from jar is pumped out ? Explain your answer.
    Ans. Observation : The balloon will sink.
    Explanation : As air is pumped out from jar, the density of air in jar decreases, so the upthrust on balloon decreases. As weight of balloon exceeds the upthrust on it, it sinks.
13. A block of wood is so loaded that it just floats in water at room temperature. What change will occur in the state of floatation, if
    (a) some salt is added to water,
    (b) water is heated ?
    Give reason.
    Ans. (a) Floats with some part outside water.
    Reason : On adding some salt to water, the density of water increases, so upthrust on block of wood increases and hence the block rises up till the weight of salty water displaced by the submerged part of block becomes equal to the weight of block. (b) Sinks.
    Reason : On heating, the density of water decreases, so upthrust on block decreases and weight of block exceeds the upthrust due to which it sinks.
14. A body of volume *V* and density ρ_s, floats with volume *v* inside a liquid of density ρ_L. Show that $\frac{v}{V} = \frac{\rho_s}{\rho_L}$.
15. Why is the floating ice less submerged in brine than in water ?
    Ans. Density of brine is more than the density of water.
16. A man first swims in sea water and then in river water.
    (i) Compare the weights of sea water and river water displaced by him.
    (ii) Where does he find it easier to swim and why?
    Ans. (i) 1 : 1 (in each case the weight of water displaced will be equal to the weight of man) (ii) In sea water because the density of sea water is more than that of river water so his weight is balanced in sea water with his less part submerged inside it.

17. An iron nail sinks in water while an iron ship floats on water. Explain the reason.

18. What can you say about the average density of a ship floating on water in relation to the density of water ?

Ans. Average density of ship is less than the density of water.

19. A piece of ice floating in a glass of water melts, but the level of water in glass does not change. Give reason.

[Hint : Ice contracts on melting.]

20. A buoy is held inside water contained in a vessel by tying it with a thread to the base of the vessel. Name the *three* forces that keep the buoy in equilibrium and state the direction in which each force acts.

Ans. (i) Weight of buoy vertically downwards, (ii) upthrust of water on buoy vertically upwards, and (iii) tension in thread vertically downwards.

21. A loaded cargo ship sails from sea water to river water ? State and explain your observation.

22. Explain the following :
   (a) Icebergs floating in sea are dangerous for ships.
   (b) An egg sinks in fresh water, but floats in a strong salt solution.
   (c) A toy balloon filled with hydrogen rises to the ceiling, but if filled with carbon dioxide sinks to the floor.
   (d) As a ship in harbour is being unloaded, it slowly rises higher in water.
   (e) A balloon filled with hydrogen rises to a certain height and then stops rising further.
   (f) A ship submerges more as it sails from sea water to river water.

Multiple choice type :

1. For a floating body, its weight W and upthrust F_B on it are related as :
   (a) $W > F_B$ (b) $W < F_B$
   (c) $W = F_B$ (d) nothing can be said.

   Ans. (c) $W = F_B$

2. A body of weight W is floating in a liquid. Its apparent weight will be :
   (a) equal to W (b) less than W
   (c) greater than W (d) zero. **Ans.** (d) zero

3. A body floats in a liquid A of density ρ_1 with a part of it submerged inside liquid while in liquid B of density ρ_2 totally submerged inside liquid. The densities ρ_1 and ρ_2 are related as :
   (a) $\rho_1 = \rho_2$ (b) $\rho_1 < \rho_2$
   (c) $\rho_1 > \rho_2$ (d) nothing can be said

   Ans. (c) $\rho_1 > \rho_2$

Numericals :

1. A rubber ball floats on water with its 1/3rd volume outside water. What is the density of rubber ?

   Ans. 667 kg m^{-3}

2. A block of wood of mass 24 kg floats on water. The volume of wood is 0·032 m^3. Find :
   (a) the volume of block below the surface of water,
   (b) the density of wood.
   (Density of water = 1000 kg m^{-3})

   Ans. (a) 0·024 m^3 (b) 7·5 × 10^2 kg m^{-3}

3. A wooden cube of side 10 cm has mass 700 g. What part of it remains above the water surface while floating vertically on the water surface ?

   Ans. 3 cm height

4. A piece of wax floats on brine. What fraction of its volume is immersed ?
   Density of wax = 0·95 g cm^{-3}, Density of brine = 1·1 g cm^{-3}. **Ans.** 0·86

5. If the density of ice is 0·9 g cm^{-3}, what portion of an iceberg will remain below the surface of water in a sea ? (Density of sea water = 1·1 g cm^{-3})

   Ans. $\frac{9}{11}$th (or 0·818th) part.

6. A piece of wood of uniform cross section and height 15 cm floats vertically with its height 10 cm in water and 12 cm in spirit. Find the density of (i) wood and (ii) spirit.

   Ans. (i) 0·667 g cm^{-3}, (ii) 0·833 g cm^{-3}

7. A wooden block floats in water with two-third of its volume submerged. (a) Calculate the density of wood. (b) When the same block is placed on oil, three-quarter of its volume is immersed in oil. Calculate the density of oil.

   Ans. (a) 667 kg m^{-3}, (b) 889 kg m^{-3}

8. The density of ice is 0·92 g cm^{-3} and that of sea water is 1·025 g cm^{-3}. Find the total volume of an iceberg which floats with its volume 800 cm^3 above water. **Ans.** 7809·5 cm^3

9. A weather forecasting plastic balloon of volume 15 m^3 contains hydrogen of density 0·09 kg m^{-3}. The volume of an equipment carried by the balloon is negligible compared to its own volume. The mass of empty balloon alone is 7·15 kg. The balloon is floating in air of density 1·3 kg m^{-3}. Calculate : (i) the mass of hydrogen in the balloon, (ii) the mass of hydrogen and balloon, (iii) the total mass of hydrogen, balloon and equipment if the mass of equipment is x kg, (iv) the mass of air displaced by balloon and (v) the mass of equipment using the law of floatation.

   Ans. (i) 1·35 kg (ii) 8·5 kg (iii) (8·5 + x) kg (iv) 19·5 kg (v) 11 kg

6 HEAT AND ENERGY

Syllabus :

(i) *Concepts of heat and temperature.*

Scope – Heat as energy; SI unit, joule, 1 cal = 4·186 J exactly.

(ii) *Anomalous expansion of water.*

Scope – Anomalous expansion of water, graphs showing variation of volume and density of water with temperature in the 0 to 10°C range. Hope's experiment and consequences of anomalous expansion.

(iii) *Energy flow and its importance.*

Scope – Understanding the flow of energy as linear and linking it with the laws of thermodynamics — 'energy is neither created nor destroyed' and 'no energy transfer is 100% efficient'.

(iv) *Energy sources. Renewable versus non-renewable sources (elementary ideas with example), energy degradation.*

Scope – Solar, wind, water and nuclear energy (only qualitative discussion of steps to produce electricity).

Renewable energy : Bio gas, solar energy, wind energy, energy from falling of water, run-of-the river schemes, energy from waste, tidal energy, etc. Issues of economic viability and ability to meet demands.

Non-renewable energy : Coal, oil, natural gas, inequitable use of energy in urban and rural areas, use of hydroelectrical power for light and tube-wells.

Energy degradation : Meaning and examples..

(v) *Green house effect and global warming.*

Scope – Meaning and impact on the life on earth; projections for the future; what needs to be done.

(A) HEAT AND TEMPERATURE; ANOMALOUS EXPANSION

6.1 CONCEPT OF HEAT (HEAT AS ENERGY)

It is our common experience that on rubbing our palms, they get heated ; on passing electric current in a metallic wire, the wire gets heated; on burning coal, we get heat; on pumping air in a bicycle tube, the barrel of pump gets heated. In all these cases, heat is produced either by doing work or by providing energy in some form other than heat. On rubbing palms and on pumping air in a bicycle tube, heat is produced by doing work *i.e.*, from mechanical energy, while on passing current in a metallic wire, heat is obtained from electrical energy and on burning coal, heat is obtained from chemical energy. Thus *heat is also a form of energy.*

Each body is made up of molecules. The molecules are in random motion and each molecule exerts a force of attraction on other molecules. Thus molecules possess energy and the heat energy of a body is the internal energy* of its molecules. A hot body has more internal energy than an identical cold body. When a hot body is kept in contact with a cold body, the cold body warms up and the hot body cools down *i.e.*, the internal energy of cold body increases and that of the hot body decreases. Thus energy is transferred from the hot body to the cold body when they are placed in contact. The energy which flows from hot body to the cold body is called the *heat energy* or simply the *heat.*

On touching, a body appears hot to us when heat energy flows from that body to our hand, while it appears cool to us when heat energy flows from our hand to the body.

Example **:** If we touch warm water, we feel hot because heat energy from warm water passes to our hand. Similarly, if we touch a cube of ice, we feel cool because heat energy from our hand passes to the cube of ice.

Thus we can define heat as follows :

Heat is the internal energy of molecules constituting the body. It flows from a hot body to a cold body.

* *Total internal energy is equal to the sum of internal kinetic energy due to molecular motion and internal potential energy due to molecular attractive forces.*

Unit of heat

The unit of heat is same as that of energy. The S.I. unit of heat is joule (abbreviated as J) and its C.G.S. unit is erg, where

$$1 \text{ J} = 10^7 \text{ erg} \quad ...(6.1)$$

Other units of heat are calorie (cal) and kilocalorie (kcal), where

$$1 \text{ kilocalorie} = 1000 \text{ calories} \quad ...(6.2)$$

The units calorie and joule are related as :

$$1 \text{ cal} = 4{\cdot}186 \text{ J (or nearly } 4{\cdot}2 \text{ J)} \quad ...(6.3)$$

6.2 CONCEPT OF TEMPERATURE

When a hot body is kept in contact with a cold body, it is noticed that after some time, the hot body becomes less hot and the cold body becomes less cold. Obviously, this is because of the *flow of heat from hot body to the cold body*. The body which imparts heat is said to be at a higher temperature than the body which receives heat. Thus, *temperature determines the direction of flow of heat.*

When a body receives heat energy, the particles constituting the body start vibrating more vigorously and its temperature rises provided its physical state or dimensions remain unchanged.

Thus temperature is defined as below.

> *Temperature is a quantity which tells the thermal state of a body (i.e., the degree of hotness or coldness of the body). It determines the direction of flow of heat when two bodies at different temperatures are placed in contact.*

If there is no transfer of heat between the two bodies placed in contact, they are said to be at the same temperature, but it does not mean that they have equal amount of heat in them. In fact, temperature alone does not tell us the quantity of heat energy contained in a body. Experimentally, we find that by imparting same quantity of heat energy to different bodies, they get heated to different temperatures. *The amount of heat energy contained by a body depends on its mass, temperature and the material of the body.*

Unit of temperature

The S.I. unit of temperature is kelvin (symbol K). The other most common unit of temperature is degree celsius (symbol °C) and degree fahrenheit (symbol °F).

The temperature on Celsius scale and Kelvin scale are related as :

$$T \text{ K} = 273 + t \text{ °C} \quad ...(6.4)^*$$

Thus, *by adding 273 to the temperature in degree celsius, we get the temperature in Kelvin.* Actually a degree on both the Kelvin and Celsius scales is equal.

The ice point is 0°C on Celsius scale, 32°F on Fahrenheit scale and 273 K on the Kelvin scale. The steam point is 100°C on Celsius scale, 212°F on Fahrenheit scale and 373 K on the Kelvin scale. Thus there are 100 equal degrees between the ice point and steam point on both the Celsius and Kelvin scales, but 180 equal divisions on the Fahrenheit scale. Thus 1 degree on Celsius scale is $\frac{9}{5}$ degree on Fahrenheit scale.

* More precisely $T \text{ K} = 273{\cdot}15 + t$ °C

Difference between heat and temperature

Heat	Temperature
1. Heat is a form of energy obtained due to random motion of molecules in a substance	1. Temperature is a quantity which determines the direction of flow of heat on keeping the two bodies at different temperatures in contact.
2. The S.I. unit of heat is joule (J)	2. The S.I. unit of temperature is kelvin (K).
3. The amount of heat contained in a body depends on mass, temperature and material of body.	3. The temperature of a body depends on the average kinetic energy of its molecules due to their random motion.
4. Heat is measured by the principle of calorimetry.	4. Temperature is measured by a thermometer.
5. Two bodies having same quantity of heat may differ in their temperature.	5. Two bodies at same temperature may differ in the quantities of heat contained in them.
6. When two bodies are placed in contact, the total amount of heat is equal to the sum of heat of the individual bodies.	6. When two bodies at different temperatures are placed in contact, the resultant temperature is a temperature in between the two temperatures.

The zero of the Kelvin scale is called *absolute zero* and it is at a temperature when molecular motion ceases. It is at –273°C *i.e.* 0 K = –273°C.

The temperature on Celsius and Fahrenheit scales are related as : $\frac{C}{5} = \frac{F-32}{9}$ ....(6.5)

6.3 THERMAL EXPANSION

Almost all substances (solids, liquids and gases) expand on heating and contract on cooling.

The expansion of a substance on heating is called the thermal expansion of that substance.

A solid has a definite shape, so when a solid is heated, it expands in all directions *i.e.*, the length, area and volume, all increase on heating. The increase in length is called the *linear expansion*, the increase in area is called the *superficial expansion* and the increase in volume is called the *cubical expansion*. The liquids and gases do not have a definite shape, so they have only the cubical (or volume) expansion. On heating, *liquids expand more than the solids,* and *gases expand much more than the liquids.*

Some substances such as water from 0°C to 4°C, silver iodide from 80°C to 141°C and silica below –80°C contract on heating and expand on cooling. The expansion of a substance on cooling in a certain range of temperature is called the *anomalous expansion* of that substance. Here we shall study the anomalous expansion of water.

6.4 ANOMALOUS EXPANSION OF WATER

If we take some water at 0°C and start heating it, we find that it contracts (instead of expanding) in the temperature range from 0°C to 4°C. On heating it further above 4°C, it expands. Similarly, if water initially at a temperature above 4°C is cooled, it contracts till the temperature of water reaches 4°C. On further cooling it below 4°C to 0°C, it expands. This unusual expansion of water on cooling it in the temperature range 4°C to 0°C, is called *anomalous expansion of water*. Thus,

The expansion of water when it is cooled from 4°C to 0°C, is known as anomalous expansion of water.

Fig. 6.1 shows the variation in volume of 1 g of water with temperature in the range

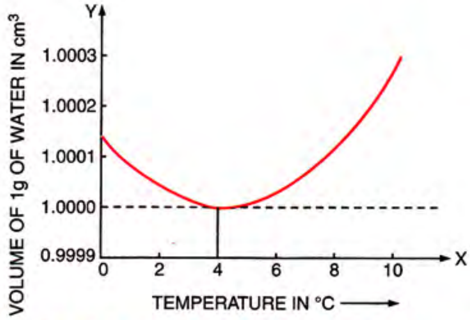


Fig. 6.1 Variation in volume of water in range of temperature 0°C to 10°C

from 0°C to 10°C. The volume of water first *decreases* on heating it from 0°C to 4°C and then *increases* on further heating it from 4°C to 10°C. *The volume of water is thus minimum at* 4°C. For 1 g of water, the volume at 4°C is 1·0000 cm³.

Fig. 6.2 shows the variation in density of water with temperature in the range from 0°C to 10°C. When water is heated from 0°C, the density of water first *increases* from 0°C to 4°C and then *decreases* above 4°C to 10°C. On the other hand, on cooling water from 10°C, the density of water first *increases* up to 4°C and then *decreases* when it is cooled further below 4°C to 0°C. Thus *the density of water is maximum at* 4°C which is equal to 1 g cm^{-3} (or 1000 kg m^{-3}).

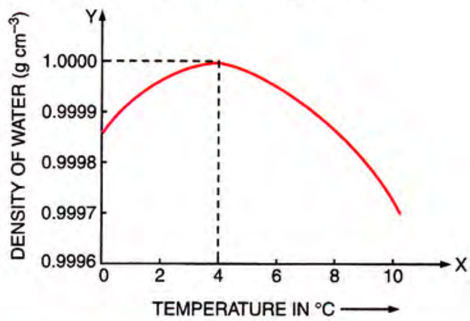


Fig. 6.2 Variation in density of water with temperature in range 0°C to 10°C

6.5 HOPE'S EXPERIMENT TO DEMONSTRATE THE ANOMALOUS EXPANSION OF WATER

In 1805, the scientist T.C. Hope devised a simple arrangement, known as Hope's apparatus for demonstrating the anomalous expansion of water. Fig 6.3 shows the Hope's apparatus.

The apparatus consists of a tall metallic cylinder provided with two side openings *P* near the top and *Q* near the bottom, fitted with thermometers T_1 and T_2 respectively. The central

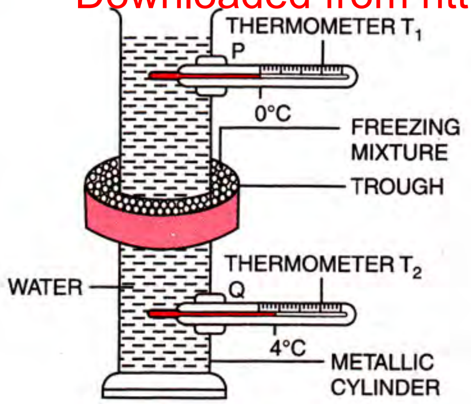


Fig. 6.3 Hope's apparatus

part of the cylinder is surrounded by a cylindrical trough containing a freezing mixture of ice and salt. The cylinder is filled with pure water at room temperature. The temperature recorded by both the thermometers is observed at a regular interval of time.

Observations : (i) Initially both the thermometers T_1 and T_2 show same temperature, (*i.e.*, room temperature).

(ii) First the temperature recorded by lower thermometer T_2 starts decreasing and finally it becomes steady at 4°C, while the temperature recorded in upper thermometer T_1 remains almost unchanged during this time.

(iii) While the temperature recorded by lower thermometer T_2 remains constant at 4°C, the upper thermometer T_1 shows a continuous fall in temperature up to 0°C and then it also becomes steady.

Thus finally the temperature recorded by upper thermometer T_1 is 0°C and that by lower thermometer T_2 is 4°C.

Fig. 6.4 shows the variation in temperature recorded by thermometers T_1 and T_2 with time.

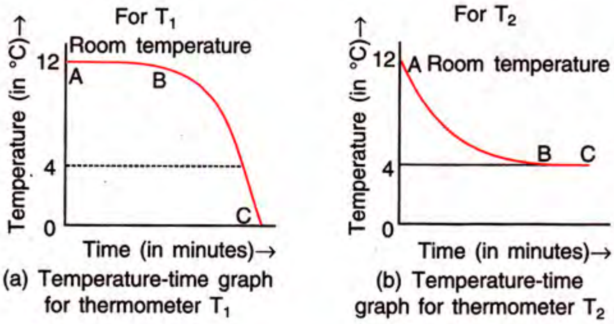


Fig. 6.4 Variation in temperature with time recorded by the thermometers T_1 and T_2

Explanation : Initially water in cylinder is at room temperature (say 12°C) which is indicated by the point *A* in the graphs. As the freezing mixture cools water in the central portion of the cylinder, water contracts and its density *increases*. Consequently the cooled water sinks to the bottom and warm water from the bottom rises up to take its place. Thus by convection, water of the lower part cools, so the reading of the lower thermometer T_2 falls rapidly. The reading of upper thermometer T_1 does not change because the temperature of water in the upper part does not change. This continues till temperature of entire water below the central portion reaches at 4°C. This is shown by the part *AB* in graphs (a) and (b). Now the reading of lower thermometer T_2 becomes steady. On further cooling below 4°C, due to anomalous expansion, water of the central portion now expands, so its density *decreases* and hence it rises up. To take its place, water from top descends down and by convection, water above the central portion cools. So the reading of upper thermometer T_1 now falls rapidly till 0°C and water near the top freezes to form ice at 0°C. Now the thermometer T_1 shows the steady temperature 0°C. This is shown by the part *BC* in graphs (a) and (b). At this stage, the *lower thermometer T_2 shows the temperature 4°C at which water has the maximum density while the upper thermometer T_1 shows the temperature of water and ice at 0°C.*

6.6 CONSEQUENCES OF ANOMALOUS EXPANSION OF WATER

(i) *The anomalous expansion of water helps in preserving the aquatic life during the very cold weather*

In cold weather (or winter), when the atmospheric temperature starts falling well below 0°C, water at the surface of a pond (or lake) initially at temperature above 4°C, begins to radiate heat to the atmosphere, so the temperature of water starts falling upto 4°C. When temperature of water at the surface falls, water contracts, so its density increases and therefore, it sinks to the bottom. This continues till temperature of entire water reaches to 4°C. Now, further cooling of top layers below 4°C results in expansion of water and so its density decreases. As a result, water does not sink

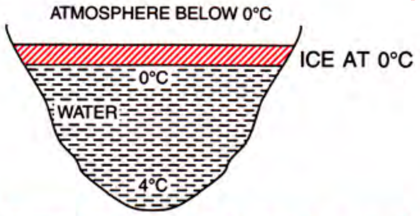


Fig. 6.5 Formation of ice at the top in a pond

further, but it remains on the surface. When the temperature of atmosphere falls below 0°C, water on the surface rejects heat to the atmosphere and gradually freezes into ice, but water well below the ice layer remains at 4°C. The water layer just below the ice in contact with it will be at 0°C. Fig. 6.5 shows the formation of ice at the surface of pond (or lake). Since ice is a *poor conductor of heat*, so ice now prevents the flow of heat from water of pond (or lake) to the atmosphere. Thus temperature of water in contact with ice is at 0°C, while the temperature of water layers below the ice gradually increases to 4°C. As a result, fish and other aquatic creatures remain alive in water of the pond (or lake), though water on the surface has frozen into ice. Nature thus protects the aquatic life during the winter season.

(ii) ***The anomalous expansion of water is responsible for the burst of water pipe lines, and destruction of crop during the very cold nights***

In winter nights, as the atmospheric temperature starts falling below 4°C, water in pipe lines expands and it exerts large pressure on the pipes, causing them to burst. Plants also die for the same reason as their capillaries burst when water expands below 4°C.

To protect the plants, the field is filled with water.

EXERCISE 6(A)

1. What is heat ? Write its S.I. unit.
2. Two bodies at different temperatures are placed in contact. State the direction in which heat will flow. **Ans.** From the body at high temperature to the body at low temperature.
3. Name the S.I. unit of heat and how is it related to the unit calorie ?
   Ans. joule (J), 1 J = 0·24 cal (nearly)
4. Define temperature and write its S.I. unit.
5. Why does a piece of ice when touched with hand, appear cool ? Explain.
   Ans. On touching ice, heat passes from our hand to the ice.
6. Distinguish between heat and temperature.
7. What do you understand by thermal expansion of a substance ?
8. Name *two* substances which expand on heating.
   Ans. Brass, Iron
9. Name *two* substances which contract on heating.
   Ans. Water from 0°C to 4°C, silver iodide from 80°C to 141°C.
10. What do you mean by anomalous expansion of water ?
    Ans. Expansion of water on cooling it from 4°C to 0°C.
11. At what temperature the density of water is maximum ? State its value.
    Ans. At 4°C, 1000 kg m^{-3}
12. State the volume changes observed when a given mass of water is heated from 0°C to 10°C. Sketch a temperature-volume graph to show the behaviour.
13. Draw a graph to show the variation in density of water with temperature in the temperature range from 0°C to 10°C.
14. A given mass of water is cooled from 10°C to 0°C. State the volume changes observed. Represent these changes on a temperature-volume graph.
15. Describe an experiment to show that water has maximum density at 4°C. What important consequences follow from this peculiar property of water ? Discuss the importance of this phenomenon in nature.
16. Deep pond of water has its top layer frozen during winter. State the expected temperature of water layer (i) just in contact with ice, (ii) at the bottom of pond. **Ans.** (i) 0°C (ii) 4°C
17. Draw a diagram showing the temperature of various layers of water in an ice covered pond.
18. Explain the following :
    (a) Water pipes in colder countries often burst in winter.
    (b) In winter, water tank (or ocean) starts freezing from the surface and not from the bottom.

(c) Fishes survive in ponds even when the atmospheric temperature is well below 0°C.

(d) A hollow glass sphere which floats with its entire volume submerged in water at 4°C, sinks when water is heated above 4°C.

(e) A glass bottle completely filled with water and tightly closed at room temperature, is likely to burst when kept in the freezer of a refrigerator.

Multiple choice type :

1. Calorie is the unit of :
   (a) heat (b) work
   (c) temperature (d) food
   Ans. (a) heat

2. 1 J equals to :
   (a) 0·24 cal (b) 4·18 cal
   (c) 1 cal (d) 1 kcal
   Ans. (a) 0·24 cal

3. S.I. unit of temperature is :
   (a) cal (b) joule
   (c) celsius (d) kelvin
   Ans. (d) kelvin

4. Water is cooled from 4°C to 0°C. It will :
   (a) contract
   (b) expand
   (c) first contract, then expand
   (d) first expand, then contract. **Ans.** (b) expand

5. Density of water is maximum at :
   (a) 0°C (b) 100°C
   (c) 4°C (d) 15°C **Ans.** (c) 4°C

(B) ENERGY FLOW AND ITS IMPORTANCE

6.7 ENERGY FLOW IN AN ECOSYSTEM

A unit composed of biotic components (*i.e.*, producers, consumers and decomposers) and abiotic components (*i.e.*, light, heat, rain, humidity, inorganic and organic substances) is called an *ecosystem*.

The existence of living beings such as plants and animals depends on the flow of energy in them. Energy is needed for all the biotic activities. The most significant source of energy for all ecosystems is the *sun*.

The energy received on the earth from the sun is utilised in different ways. Nearly 56-60% part of the incident energy is absorbed by the atmosphere, nearly 10% is utilised in heating of water and land, and only 8% falls on plants. Plants absorb most of the energy falling on them. Out of the absorbed energy, plants use only 0·02% in photosynthesis for producing their food. They are called the *producers*.

Food chain : In ecosystem, photosynthetic plants and bacteria act as *producers*. The food synthesized by producers is utilised by *primary consumers* (such as krill). The primary consumers are eaten by the *secondary consumers* (such as small fish) and in turn they are consumed by the *tertiary consumers* (such as large fish). The tertiary consumers may be eaten by man. The man may be the *last consumer* in this chain of energy transfer when he eats the fish. This simple food chain is shown in Fig. 6.6.

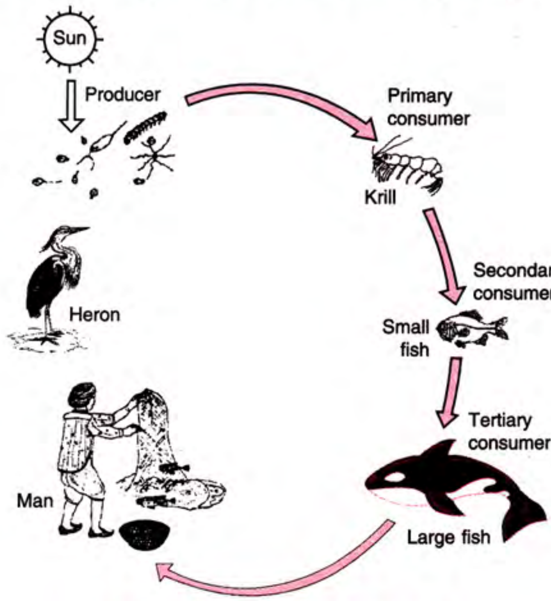


Fig. 6.6 The simple food chain

Energy flow : Fig. 6.7 shows the energy flow in the ecosystem. The *producers* (photosynthetic plants) synthesize organic substances by the process of photosynthesis (*i.e.*, they bind the simple compounds with the help of solar energy into the complex organic substances). The chemical energy so stored in plants is called the *gross primary production*. The producers themselves first use the

synthesized organic substances in the process of respiration in which some energy is used in oxidation of organic substances. The rest of the energy, called the *net primary production*, is stored for the growth, development and important metabolic processes. In Fig. 6.7, the gross primary production by the producers is 20,810 cal energy, out of which 11,977 cal energy is used in the respiration and the net primary production is 8,833 cal energy.

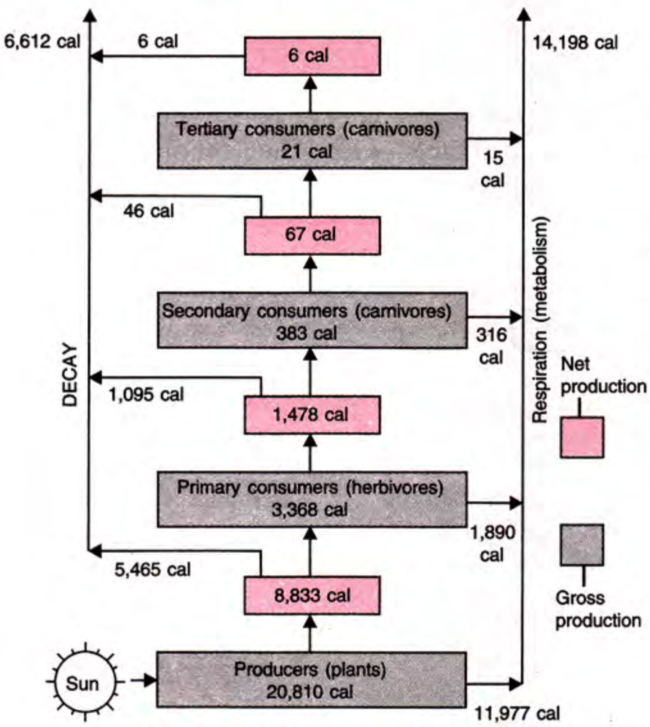


Fig. 6.7 Energy flow in ecosystems

Next the *primary consumers* (herbivores) obtain their food from the producers, so they obtain only a small part of energy from the producers and the rest is wasted in decay of producers. A small part of the energy obtained by the primary consumers is utilized in respiration through which they perform metabolic processes of their body and the remaining part is stored in them as food. In Fig. 6.7, the primary consumers obtain only 3,368 cal energy from the producers and rest of the energy 5,465 cal is wasted in their decay. Then out of 3,368 cal energy which the primary consumers obtain from the producers, 1,890 cal energy is used up in respiration and 1,478 cal energy is stored as food.

Afterwards, a small part of the energy stored as food in the primary consumers is obtained by the *secondary consumers* (carnivores). They again make use of a part of the energy in respiration and rest is stored in them as food. In Fig. 6.7, the secondary consumers obtain only 383 cal energy from the primary consumers and rest of the energy 1,095 cal is wasted in their decay. The secondary consumers utilise 316 cal energy in respiration and rest of the energy 67 cal is stored in them as food.

By repeating the sequence, the *tertiary consumers* (carnivores) obtain energy as food from the secondary consumers and utilise a small part of it in respiration and remaining energy is wasted in their decay and decomposition. In Fig. 6.7, the tertiary consumers obtain only 21 cal energy from the secondary consumers and rest of the energy (*i.e.*, 46 cal) is wasted in their decay. Out of the 21 cal energy obtained by the tertiary consumers, 15 cal energy is used in respiration and 6 cal energy is wasted in their decay.

The energy flow in ecosystems is thus linear i.e., it moves in a fixed direction. At the end, the energy reaches to the degraded (or unuseful) state.

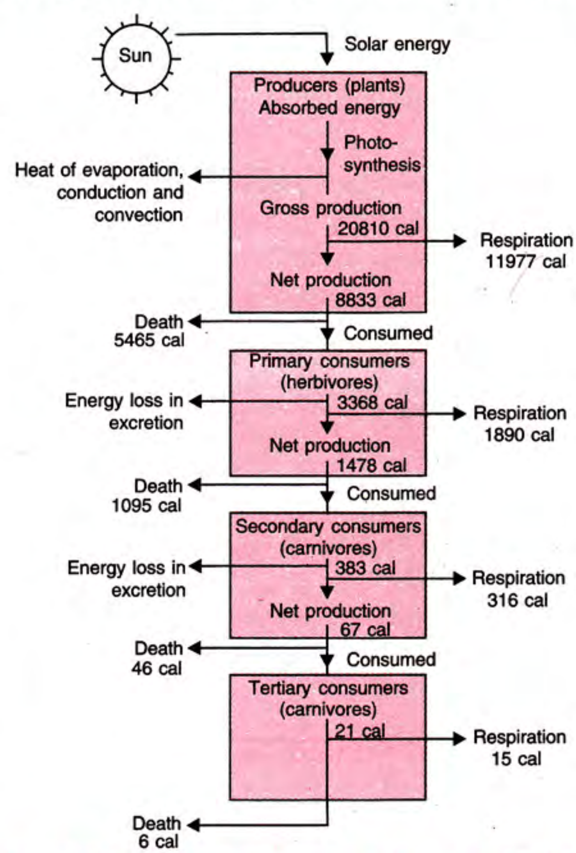


Fig. 6.8 Energy flow in ecosystem in form of a food chain

It does not return to the sun to make the process cyclic.

The energy flow in the ecosystem can also be understood in form of a food chain shown in Fig. 6.8.

6.8 APPLICATION OF LAWS OF THERMODYNAMICS IN ENERGY FLOW

The flow of energy in the process of entrance, transformation and diffusion in ecosystem is governed by the laws of thermodynamics.

According to the first law of thermodynamics, *the energy can be transformed from one form to the other form, but it can neither be created nor destroyed*. When certain amount of one form of energy is destroyed, then the same amount of another form of energy is created as shown in Fig. 6.7

According to the second law of thermodynamics, when energy is put to work, *a part of it is always converted in unuseful form as heat mainly, due to friction and radiation.* In all such cases the total sum of useful and unuseful energy remains constant. In Fig. 6.7, the energy used in respiration and in decay (or death) appears as unuseful heat energy because this energy does not reach to the consumer of next stage. So just like a machine, in ecosystem also the energy transfer is not 100% efficient, a portion of the transferred energy always goes to unuseful form in accordance with the second law of thermodynamics.

EXERCISE 6(B)

1. What is an ecosystem ? Name its *two* components.
2. What is the source of energy for all ecosystems ?
3. State the importance of green plants in an ecosystem.
4. Differentiate between the producers and consumers.
5. State the functions of decomposers in an ecosystem.
6. What is a food chain ?
7. Draw a simple diagram showing a food chain.
8. Describe the energy flow in an ecosystem.
9. State the law which governs the energy flow in an ecosystem.
10. Show that the energy flow in an ecosystem is linear.
11. Draw a simple diagram showing the energy flow in a food chain.
12. Draw a diagram to show that the energy flow in an ecosystem is governed by the law of conservation of energy.

Multiple choice type :

1. Food chain begins with :
   (a) respiration (b) photosynthesis
   (c) decomposition (d) decay.
   Ans. (b) photosynthesis.
2. The source of energy in an ecosystem is :
   (a) sun (b) decayed bodies
   (c) green plants (d) sugar.
   Ans. (a) sun.
3. Energy enters in a food chain through :
   (a) primary consumers
   (b) secondary consumers
   (c) tertiary consumers
   (d) producers.
   Ans. (d) producers.
4. The place of human being in food chain in an ecosystem is as a :
   (a) producer (b) consumer
   (c) decomposer (d) both (a) & (b).
   Ans. (b) consumer.

(C) ENERGY SOURCES

6.9 SOURCES OF ENERGY

We require energy in every activity of our life. For example, energy is required to cook food, to light homes, to run gadgets, to move vehicles, to run T.V., cinema, radio, etc. We need energy for production in factories and also for crops in fields. To meet most of these requirements, the energy needed is in form of heat and electricity. For example, we need heat energy for cooking food and this heat energy is obtained by burning the fuels such as coal, wood, kerosene or cooking gas. We need electricity to run electric motors, fans, etc. and it is obtained from coal, hydro-energy or nuclear energy.

Characteristics of a source of energy : *A source of energy should be such that it can provide an adequate amount of useful energy at a steady rate over a long period of time. It should be safe and convenient to use, economical and easy to store and transport.*

Classification of sources of energy : From the point of *view of availability*, the energy sources are divided into the following *two* groups:

(1) renewable or non-conventional sources of energy, and

(2) non-renewable or conventional sources of energy.

6.10 RENEWABLE OR THE NON-CONVENTIONAL SOURCES OF ENERGY

A natural source providing us energy continuously is called a renewable (or non-conventional) source of energy. Sun is the main source of energy for us on the earth. The energy harnessed from the natural sources like wind, flowing water, tides, ocean waves and biogas is directly or indirectly derived from the energy of the sun. We can use these sources as long as the earth continues to receive heat and light from the sun. Apart from these sources, geo-thermal energy and nuclear energy are the other sources of energy which can provide us energy over a long period of time. These sources of energy can be used again and again and will never get exhausted.

Although the wood, obtained from trees, is also considered a renewable source of energy, but trees usually take more than 15 years to grow fully, therefore, renewal of wood as source of energy takes a long time. Further, *cutting of trees on a large scale causes depletion of forests which results in global warming and environmental imbalance. Hence use of wood as a source of energy must be avoided.*

Thus, the main sources of renewable energy are : (i) Sun (ii) Wind (iii) Flowing water (Hydro) (iv) Bio mass and bio fuels from waste (v) Tides (vi) Oceans (vii) Geo-thermal spots and (viii) Nuclear fuel.

(i) Sun as source of energy : Sun is the main source of various types of energy. *The energy obtained from sun is called the 'solar energy.* In the interior of the sun, nuclear fusion reactions generate huge amount of energy which is radiated out continuously in all directions in space. Since the sun is very far from the earth, we receive only a very small fraction of the total solar energy.

The solar energy that reaches earth is neither uniform nor equal at all places. It changes daily even at one place. It also varies during a day. The average solar energy reaching the upper atmosphere of earth per second on an area of 1 metre^2 is called the *solar constant* and it is estimated to be nearly 1·34 kW m^{-2}. The solar energy reaching the earth is absorbed by land, plants and water bodies like rivers, lakes and oceans. The solar energy absorbed by land and water bodies cause winds, storms, rains, snow falls and sea waves, etc. while the solar energy absorbed by plants is utilized by them in preparing their food by the process of photosynthesis.

(ii) Wind as source of energy : The large mass of moving air is called wind. Due to motion, it has kinetic energy. *The kinetic energy of wind is called the wind energy.*

Indirectly wind energy comes from solar energy. The sun rays falling on earth heat different areas of earth unequally. Due to (i) unequal heating of different areas of earth, (ii) rotation of earth and (iii) local convection currents, we have different wind cycles.

From the very early days, we have been using energy possessed by wind for various purposes such as in removing husk from grains, in propelling sail boats in rivers and seas, in moving vehicles for transportation and in windmills to draw water from the ground and to grind grains.

(iii) Flowing water as a source of energy: *The kinetic energy possessed by the flowing water is called the hydro energy.*

Hydro energy too comes indirectly from the sun. The solar energy is responsible for water cycle in nature. Water in oceans, rivers, lakes, etc. absorbs solar energy and it then evaporates to form clouds. The clouds move due to air currents and ultimately water comes back on earth in the form of rain and snow.

Man has been utilizing for centuries the energy of flowing water in rivers for rotating the wheels of water mill used to drive the flour mill in remote hilly areas and for transporting heavy logs of wood from forests in hilly areas to the downstream areas in planes.

(iv) Bio mass as source of energy : The wastes and dead parts of living beings like plants, trees and animals, is called *bio mass.* They contain carbon compounds. *The chemical energy stored in the bio mass is called the bio energy*. Thus, bio energy also comes from solar energy. Bio mass such as wood, cattle dung, crop residues and agriculture wastes like bagasse have been traditionally used as fuel to produce heat energy for domestic as well as commercial purposes.

Bio mass is also used to produce bio gas by its decomposition in the absence of oxygen. The main constituent of bio gas is methane (65%) and rest is a mixture of carbon dioxide, hydrogen and hydrogen sulphide. Bio gas is used as a fuel to run engines and for generating electricity. In India, we use *two* types of bio gas plants : (1) the floating gas holder type and (2) the fixed dome type. They are also called **Gobar gas plants** because the main bio mass used in these plants is called *slurry* which is the mixture of animal dung (or gobar) in water.

(v) Tides as source of energy : The rise of ocean water near the coast is called *high tide* and fall of ocean water is called *low tide*. This rise and fall of tidal waves occur twice a day in oceans. *The energy possessed by rising and falling water in tides is known as tidal energy.*

Tidal energy is harnessed for producing electricity by constructing a dam across a narrow opening to the sea. But this is not a major source of energy because of the following *two* reasons :

(1) The rise and fall of sea water during tides is not enough to generate electricity on a large scale.

(2) There are very few sites which are suitable for building the tidal dams.

(vi) Oceans as source of energy : Water in oceans possesses energy in *two* forms : (a) ocean thermal energy and (b) oceanic (or sea) waves energy.

(a) Ocean thermal energy : Water at the surface of an ocean gets heated by absorbing the heat of sun, while water at its deeper levels remains cold. Thus, there is a difference in temperature of water at the surface and at deeper levels of an ocean. This difference in temperature is found to be up to 20°C. *The energy available due to the difference in temperature of water at the surface and at deeper levels of ocean is called the ocean thermal energy (OTE).* Obviously, this energy also comes indirectly from the sun.

Ocean thermal energy is harnessed for producing electricity by a device called *ocean thermal energy conversion power plant* (OCTEC power plant).

(b) Oceanic (or sea) waves energy : Due to the wind blowing on the surface of oceans, waves move at high speed on its surface which are called the oceanic waves (or sea waves). Due

to their high speed, they carry tremendous amount of kinetic energy with them. Thus, *the kinetic energy possessed by such fast moving oceanic (or sea) waves is called the oceanic (or sea) waves energy.* This energy also comes indirectly from the sun.

Sea waves energy can also be harnessed to produce electricity, but so far it has not become possible to produce electricity from sea waves energy on a large scale. However, models have been made to generate electricity from oceanic waves.

(vii) Geo thermal spots as source of energy : At some places, rocks below the surface of earth are very hot. Such places are known as *hot spots. The heat energy possessed by rocks inside the earth is called the geo thermal energy.*

Geo thermal energy is harnessed to produce electricity. The rocks present at hot spots, heat the underground water and turn it into steam, which gets compressed at high pressure between the rocks. By drilling holes into the earth up to the hot spots, steam is extracted through pipes which is utilized to rotate the turbine connected to the armature of an electric generator to produce electricity.

In India, there are very few places where geothermal energy is harnessed to produce electricity. One such place is in Madhya Pradesh. However, in USA and Newzealand, there are a number of geo thermal energy based power plants.

(viii) Nuclear fuel as source of energy : When uranium nucleus is bombarded with a slow neutron, it splits into two nearly equal light nuclei and a large amount of energy is released. This phenomenon is called *nuclear fission*. Similarly, when two light nuclei combine to form a heavy nucleus at a very high temperature ($\approx 10^7$ K) and high pressure, a tremendous amount of energy is released. This phenomenon is called *nuclear fusion*. In both these processes, the origin of energy is the loss in mass *i.e.*, the sum of masses of the products of reaction is less than the sum of masses of reactants and this loss in mass is converted into energy E according to the Einstein's mass-energy equivalence relation $E = mc^2$, where c ($=3 \times 10^8$ m s^{-1}) is the speed of light and m is the loss in mass. This energy is known as nuclear energy.

In fission reaction of one uranium nucleus, nearly 200 MeV energy is released and *two* or *three* neutrons are also emitted. If number of uranium nuclei present are more, each neutron emitted in the fission reaction of a uranium nucleus causes fission in the new uranium nuclei and thus a chain of nuclear fission reactions occurs, which once started continues till the entire uranium is exhausted. As a result of such an *uncontrolled* chain reaction, more and more energy is produced which may cause an explosion. An *atom bomb* is based on this principle. But to utilize the energy produced in the process of fission for constructive use (such as to produce electricity), the chain reaction is *controlled* by absorbing some neutrons with the help of cadmium rods. This is done in a *nuclear reactor.*

So far it has not become possible to harness energy by the process of nuclear fusion.

6.11 NON-RENEWABLE OR THE CONVENTIONAL SOURCES OF ENERGY

The sources of energy which have accumulated in nature over a very long period and cannot be quickly replaced when exhausted, are called the non-renewable or conventional sources of energy. Coal, petroleum and natural gas known as fossil fuels are non-renewable sources. They are formed by the decomposition of the remains of plants and animals buried under the earth, millions of years ago. Thus, the formation of fossil fuels have occurred over millions of years due to certain very slow changes under special circumstances. If they are being used extensively, their known reserves will soon deplete and once exhausted, they cannot be regenerated soon.

The common non-renewable sources of energy are : (i) *coal,* (ii) *petroleum* and (iii) *natural gas.*

(i) Coal : *Coal is a non-renewable source made up of complex compounds of carbon, hydrogen and oxygen along with some free carbon and compounds of nitrogen and sulphur.* It is found in deep mines under the surface of earth. In India, coal mines are found in Jharkhand, West Bengal, Orissa and Chattishgarh. Since coal is found in abundance in our country, it is the most common source of energy for us.

(ii) Petroleum : *Petroleum is a dark coloured viscous liquid* also called crude oil. It is a non-renewable source of energy which is found under the earth's crust trapped in rocks. It is called petroleum because petroleum means rock oil. *It is a complex mixture of many hydrocarbons with water, salt, earth particles and other compounds of carbon, oxygen, nitrogen and sulphur.* It is lighter than water and does not mix with it. Petroleum is obtained by drilling oil wells into the earth's crust at its reservoirs. In India, the reservoirs of petroleum have been found in Assam and Mumbai.

The crude petroleum extracted from wells is not suitable to be used as a fuel in its natural form. It has to be purified (or refined) to obtain different useful components. *The process of separating useful components from crude petroleum is called refining which is done by fractional distillation in big oil refineries set up for this purpose.*

The petroleum gas obtained as a by-product from the fractional distillation of petroleum contains mainly the butane and a small amount of propane and ethane. These gases burn readily and produce a lot of heat. Hence the petroleum gas can be used as a good fuel.

Butane, propane and ethane are in gaseous states at ordinary pressure, but they can be easily liquefied under pressure. *The petroleum gas liquefied under pressure is called the liquefied petroleum gas (or LPG)* which is used in domestic gas stoves as fuel for heating purposes. It is stored in gas cylinders after mixing a strong smelling substance called ethyl mercaptan (C_2H_5SH) so that the gas leakage, if any, from the cylinder can easily be detected.

(iii) Natural gas : Natural gas is also a non-renewable source of energy which is found deep under the earth's crust either alone or above the petroleum reservoirs. It is also obtained by digging wells into the earth. From some wells we can extract only the natural gas, while from others both the natural gas and petroleum. In India, there are a number of natural gas fields such as in Tripura, Jaisalmer, off shore area of Mumbai and in the Krishna-Godavari delta. The main component of natural gas is methane (up to 95%) along with small quantities of ethane and propane. It easily burns to produce heat.

Distinction between the renewable and the non-renwable sources of energy

Renewable sources	Non-renewable sources
1. These are the sources from which energy can be obtained continuously over a long period of time.	1. These are the sources from which energy can not be continuously obtained over a long period of time.
2. They are the non-conventional sources.	2. They are the conventional sources.
3. These are the natural sources which will not get exhausted.	3. These are the natural sources which will get exhausted with the time.
4. These sources can be regenerated.	4. These sources can not be regenerated.
Examples : Sun, wind, flowing water (hydro), bio mass (waste), tides, oceans, geo thermal spots and nuclear fuel.	*Examples* : Coal, petroleum and natural gas.

6.12 JUDICIOUS USE OF ENERGY

It is not possible to harness energy sufficent for our requirement from the non-conventional sources, so we have to make use of the conventional sources also. But the conventional sources of energy (*i.e.*, fossil fuels) are limited and non-renewable, so the constant use of them will create an energy crisis in the coming future. Therefore the following measures must be taken for the judicious use of energy.

(1) The fossil fuels such as coal, petroleum, etc. should be used only for limited

purposes when no other alternative source of energy is available.

(2) Wastage of energy should be avoided.

(3) Cutting of trees must be banned and more and more trees should be planted.

(4) Efforts must be made to make use of energy in community (or groups).

(5) The use of energy in urban areas is much more than in the rural areas. In rural areas, the use of renewable sources of energy is easier than in urban areas. In rural areas, we can use bio gas, wind energy, hydro energy for running lights and tube wells.

(6) Such techniques should be developed by which in near future, we may make use of the renewable sources such as solar energy, wind energy, hydro energy, bio energy, ocean energy, etc. as much as possible to meet our requirements.

(7) Efforts must be made to obtain nuclear energy by the controlled nuclear fusion of deuterium nuclei present in heavy water available in sea. This will then become an endless source of energy.

In our daily life both in urban and rural area, we need energy mostly in form of electricity, so we shall now study the methods of producing electricity from the renewable sources of energy.

6.13 PRODUCTION OF ELECTRICITY FROM SOLAR ENERGY

The sun is the most vast and direct source of energy. To obtain electricity from the solar energy, *two* devices are used : a solar cell and a solar power plant. *The device which converts solar energy directly into the electricity is called a* ***solar cell***. On the other hand, *a solar heating device used to generate electricity from solar energy, is called a* ***solar power plant***.

(i) Solar cell : About a hundred years ago, it was discovered that when sunlight falls on a thin layer of selenium, an electric current is produced. Since only 0·6% of the solar energy incident on selenium could convert into electric energy, so no serious efforts were then made to produce electricity from solar energy. The first solar cell was made in 1954 which had an efficiency of only 1%. But nowadays solar cells have been made with an efficiency of up to 30%.

The solar cells are usually made from semiconductors like silicon and gallium. A semiconductor has conductivity less than that of a metal, but more than that of an insulator. At ordinary temperature, a semiconductor has a very low conductivity, but its conductivity increases either with the rise in temperature or when some impurities are added in it. If sunlight is made incident on an impurity added semiconductor, a potential difference is produced between its surfaces. This forms a solar cell. Due to this potential difference, a current flows in the circuit connected between the opposite faces of the semiconductor. Such a single solar cell of area 4 cm^2 produces a potential difference of nearly 0·4 volt to 0·5 volt due to which a current of nearly 60 milli-ampere can be obtained. To increase the efficiency, a large number of such cells are arranged over a large area so that they could collect a large amount of solar energy to produce sufficient electricity. Such an arrangement of solar cells is called a *solar panel*.

A solar panel gives electricity so long as sunlight is falling on it. Therefore a solar panel cannot produce electricity at night. To overcome this difficulty, the storage battery (or secondary cell) is charged by a solar panel during the day time and it can then be used at night to provide electricity. The solar panels are used to supply electricity in the artificial satellites and for

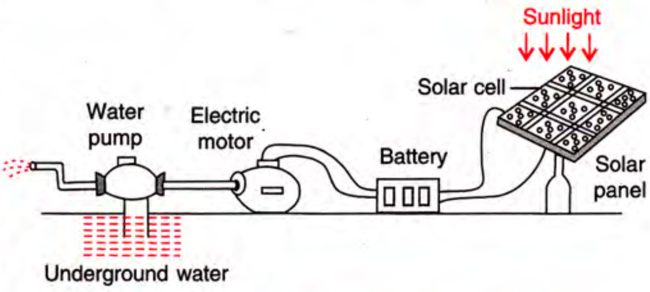


Fig. 6.9 Solar panel used for running a water pump

running water pumps, street lighting, radio and television sets in remote, inaccessible and isolated areas where conventional sources of energy are not available. Small solar cells are used in watches and calculators. Fig. 6.9 shows a solar panel used for running a water pump.

Advantages of using solar panels :

1. They do not require any maintenance.
2. They last over a long period of time.
3. Their running cost is almost nil.
4. They are most suitable for the remote, inaccessible, and isolated places where electric power lines cannot be laid.
5. They do not cause any pollution in the environment.

Disadvantages of using solar panels :

1. The initial cost of a solar panel is sufficiently high.
2. The efficiency of conversion of solar energy to electricity is low.
3. A solar panel produces d.c. electricity which cannot be directly used for many household purposes.

(ii) Solar power plant : A solar power plant is a device in which heat energy of sun is used to generate electricity. The sun rays after reflection from a large concave reflector get concentrated at its focus. The rays have sufficient heat energy which can boil water, if it is placed at the focus of the reflector. This principle is used in a solar power plant.

A solar power plant consists of a number of big concave reflectors, at the focus of which there are black painted water pipes. The reflectors concentrate the heat energy of sun rays on the pipes due to which water inside the pipes starts boiling and produces steam. The steam thus produced is used to rotate a steam turbine which drives a generator producing electricity. Such a solar power plant of capacity 50 kW has been installed at Gurgaon in Haryana.

6.14 PRODUCTION OF ELECTRICITY FROM WIND ENERGY

Nowadays wind energy is used in a wind generator to produce electricity by making use of a windmill (or wind turbine) to drive a wind generator.

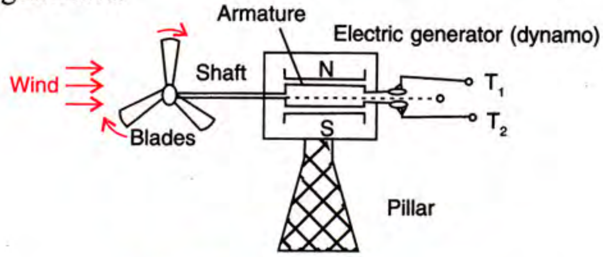


Fig. 6.10 Wind generator

Fig. 6.10 shows a wind generator in which a small electric generator (or dynamo) is placed at the top of a pillar. The armature of the dynamo is connected to the shaft attached with the blades of a wind mill. When the blowing wind strikes the blades of the wind mill (or turbine), the kinetic energy of wind changes into the rotational kinetic energy of the blades. The rotation of blades of the turbine rotates the armature of the dynamo in the magnetic field between the pole pieces N and S of a strong magnet, thus an alternating e.m.f. is produced between the terminals T_1 and T_2.

The electric power generated by a single wind mill generator is small. So to generate a sufficient amount of electric power, a large number of such wind generators are arranged over a big area called a *wind farm*, and then the electric power generated by each generator is combined together for supply to the consumers. At present in India, we are generating more than 1025 MW electric power by this technique in coastal areas of Gujarat and Tamil Nadu. It is planned to produce electric power up to 20,000 MW in our country by the use of wind energy.

Advantages of using the wind energy : (i) It does not cause any kind of pollution. (ii) It is an everlasting (*i.e.*, renewable) source.

Limitations of using the wind energy : (i) The wind farms can be established only at places near the coastal areas where wind blows around the year steadily with a speed not less than 15 km h^{-1}. (ii) A large area of land is needed for the establishment of a wind farm. (iii) The establishment of a wind farm is expensive.

6.15 PRODUCTION OF ELECTRICITY FROM WATER (*or hydro*) ENERGY

The most important use of hydro energy is to

convert it into the electrical energy by using a turbine. The electricity so obtained is called the *hydroelectric power*.

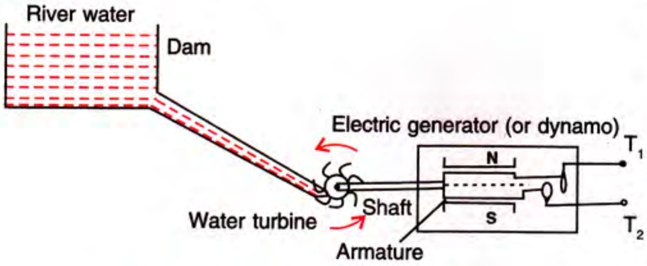


Fig. 6.11 Hydroelectric plant

Fig. 6.11 shows the principle of a hydroelectric power plant. The flowing water of river is collected in a dam at high altitude. The water stored in the dam has the potential energy. When water from dam falls on the water turbine, the potential energy of the water stored in dam changes into its kinetic energy and this kinetic energy of water is transferred to the blades of turbine as the rotational kinetic energy. As the turbine rotates, it rotates the armature of the generator (or dynamo) in the magnetic field between the pole pieces N and S of a strong magnet, due to which an alternating e.m.f. is produced between the terminals T_1 and T_2. Such a mini hydroelectric power plant can be constructed on the rivers in hilly areas across a small dam of height nearly 10 m. At present in India we are generating hydro-electricity which is only 23% of the total electricity generated by us. However, it is planned to produce nearly 4×10^{11} kWh electrical energy from the hydro energy.

Advantages of using the hydro energy : (i) It does not produce any environmental pollution. (ii) It is a renewable source of energy. (iii) The dams constructed over rivers help us in irrigation and control of floods in rivers.

Limitations of using hydro energy : (i) The flowing water is not available every where. (ii) Due to the construction of dams over the rivers, plants and animals of that place get destroyed or killed. (iii) The ecological balance in the downstream areas of rivers gets disturbed.

6.16 PRODUCTION OF ELECTRICITY FROM NUCLEAR ENERGY

It is possible to produce electricity from the nuclear energy by the controlled chain reaction of nuclear fission of a radioactive substance like uranium-235 (or plutonium-239). The set up used is called the *nuclear power plant*.

Fig. 6.12 shows the arrangement of a nuclear power plant in which the main part is the nuclear reactor. In a nuclear reactor, the chain reaction of nuclear fission of uranium-235 (or plutonium-239) is controlled by the cadmium rods. The heat energy released in the process, is absorbed by the coolant which then passes through the coils of a heat exchanger containing water. The water in heat exchanger gets heated and converts into steam. The steam is used to rotate the turbine

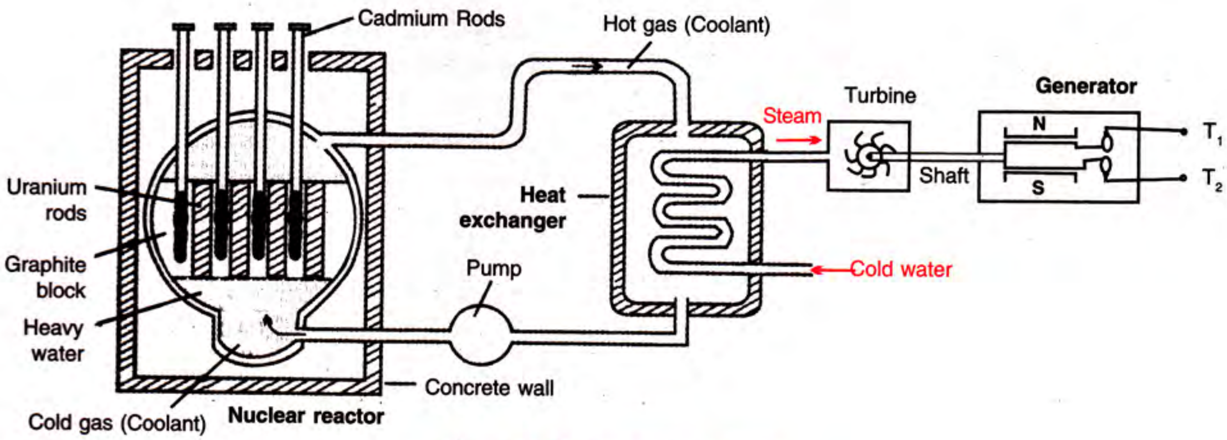


Fig. 6.12 Nuclear power plant

which in turn rotates the armature of a generator in a magnetic field and thus electricity is produced.

In India, we have *four* nuclear power plants : (i) at Tarapur in Maharashtra, (ii) at Rana Pratap Sagar near Kota in Rajasthan, (iii) at Kalpakkam in Tamil Nadu and (iv) at Narora in Uttar Pradesh, where electricity is generated by the use of nuclear energy. At present only about 3% of the total electrical power generated in India is obtained from the nuclear power plants.

Advantages of using the nuclear energy : (i) A very small amount of nuclear fuel (such as uranium-235) can produce a tremendous amount of energy. (ii) Once the nuclear fuel is loaded into a nuclear power plant, it continues to release energy over a long period.

Limitation of use of nuclear energy : (i) It is not a clean source of energy because very harmful nuclear radiations are produced in the process which are highly energetic and penetrating. These radiations cause ionisation and are very harmful to the human body, so a high standard of protection is needed for the persons working in the power plant and also for the environment. (ii) The waste obtained from the nuclear power plants causes a high degree of environmental pollution.

6.17 ENERGY DEGRADATION

In our daily life we require to transform one form of energy to the other required form of energy. By the law of conservation of energy, the given form of energy must be completely converted into the desired useful form without any loss of it. In practice, it has been observed that in transformation of energy from one form to the other desired form, the *entire energy* does not change into the desired form, but a part of it changes either to some other undesirable form (usually heat due to friction) or is lost to the surroundings due to radiation which is not useful. This conversion of energy to the undesirable (or non-useful) form is called the *dissipation of energy*. Since this part of energy is not available to us for any productive purpose, so we call this as the *degraded form of energy*. With more and more use of energy, the degraded form of energy will gradually increase, while the energy available for productive purpose will gradually decrease (since total energy remains constant).

The gradual decrease of useful energy due to radiation loss, friction, etc. is called the degradation of energy.

Examples :

(i) When we light a bulb using electricity, less than 25% of the electrical energy converts into the light energy. The remaining part of electrical energy changes into the heat in the filament and the other invisible radiations. This energy is ultimately imparted to the atmosphere in the form of vibrational kinetic energy of air molecules. The energy in this form is not useful to us.

(ii) When we run a vehicle, only a part of energy obtained from its fuel is used up in running the vehicle, major part of it is wasted in heating the moving parts of machine, in doing work against friction between the ground and its tyres and in the form of sound.

(iii) When we cook food over a fire, the major part of heat energy obtained from the fuel is radiated out in the atmosphere. This radiated energy is of no use to us. It is thus the degraded form of energy.

(iv) When electrical appliances are run by electricity, an appreciable part of electrical energy is wasted in the form of heat energy.

(v) In transmission of electricity from the power generating station, a lot of electrical energy is wasted in the form of heat energy in the line wires used for transmission.

(vi) All machines have efficiency less than 1, which implies that only a fraction of input energy is used for doing useful work and rest of the input energy is wasted or goes to the degraded form.

From the above examples, we conclude that in all processes of transfer of available form of energy to the useful form, a good fraction of energy changes to the non-productive or degraded form.

EXERCISE 6(C)

1. State *two* characteristics which a source of energy must have.
2. Name the *two* groups in which various sources of energy are classified. State on what basis are they classified.
3. What is meant by the renewable and non-renewable sources of energy ? State *two* differences between them, giving *two* examples of each.
4. Select the renewable and non-renewable sources of energy from the following :
   (a) Coal (b) Wood (c) Water
   (d) Diesel (e) Wind (f) Oil
   Ans. Renewable — (b), (c) and (e)
   Non-renewable — (a), (d) and (f)
5. Why is the use of wood as a fuel not advisable although wood is a renewable source of energy ?
6. Name *five* renewable and *three* non-renewable sources of energy.
7. What is (i) tidal, (ii) ocean and (iii) geo thermal energy ? Explain in brief.
8. What is the main source of energy for earth ?
   Ans. Sun
9. What is solar energy ? How is the solar energy used to generate electricity in a solar power plant ?
10. What is a solar cell ? State *two* uses of solar cells. State whether a solar cell produces a.c. or d.c. Give *one* disadvantage of using a solar cell.
11. State *two* advantages and *two* limitations of producing electricity from solar energy.
12. What is wind energy ? How is wind energy used to produce electricity? How much electric power is generated in India using the wind energy ?
13. State *two* advantages and *two* limitations of using wind energy for generating electricity.
14. What is hydro energy ? Explain the principle of generating electricity from hydro energy. How much hydro electric power is generated in India ?
15. State *two* advantages and *two* disadvantages of producing hydro electricity.
16. What is nuclear energy ? Name the process used for producing electricity using the nuclear energy.
17. What percentage of total electrical power generated in India is obtained from nuclear power plants ? Name *two* places in India where electricity is generated from nuclear power plants.
18. State *two* advantages and *two* disadvantages of using nuclear energy for producing electricity.
19. State the energy transformation in the following :
    (i) electricity is obtained from solar energy.
    (ii) electricity is obtained from wind energy.
    (iii) electricity is obtained from hydro energy.
    (iv) electricity is obtained from nuclear energy.
20. State *four* ways for the judicious use of energy.
21. What do you mean by degradation of energy ? Explain it by taking *two* examples of your daily life.
22. The conversion of part of energy into an unuseful form of energy is called ....
    Ans. Degradation of energy

Multiple choice type

1. The ultimate source of energy is :
   (a) wood (b) wind
   (c) water (d) sun. Ans. (d) sun
2. Renewable source of energy is :
   (a) coal (b) fossil fuels
   (c) natural gas (d) sun. Ans. (d) sun

(D) GREEN HOUSE EFFECT AND GLOBAL WARMING

6.18 GREEN HOUSE EFFECT

In 1824, Joseph Fourier discovered the green house effect. *It is the process of warming of planet's surface and its lower atmosphere by absorption of infrared radiations of long wavelength emitted out from the surface of planet.*

The solar radiations coming from sun have high energy radiations such as gamma rays, X-rays, ultra-violet rays and low energy radiations

such as visible light, infrared radiation and radio waves. Our earth's atmosphere is transparent only for visible light and *infrared radiation of short wavelength.* Gamma rays, X-rays, ultraviolet rays are absorbed by the ozone layer surrounding the earth while infrared radiation of long wavelength and radio waves are reflected back into the space by the uppermost layer of earth's atmosphere *i.e.*, ionosphere and the polar ice-caps.

The solar radiations which travel through the atmosphere of the earth, are absorbed by the clouds, earth's surface and sea water due to which earth's surface gets heated up. Now earth's surface radiates infrared radiations of *long wavelength.* For these radiations, the earth's atmosphere is opaque, so they are reflected back by the clouds and are absorbed by the gases present above the earth's surface Thus the clouds and gases prevent the long wavelength infrared radiation from escaping into the space, and keeps the earth's surface warm. Fig. 6.13 shows the green house effect.

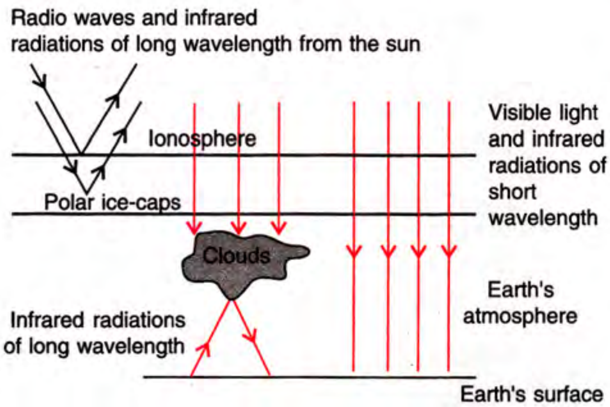


Fig. 6.13 Green house effect

The gases which are the good absorber of long wavelength infrared radiation are called the *green house gases*. They are : carbon dioxide, water vapours, methane and chlorofluorocarbons. These gases contribute in trapping the heat energy within the atmosphere. *The naturally occuring green house gases have an average warming effect of nearly* 33°C *so that the average temperature on earth's surface is about* 15·5°C *(or* 60°F*)*. In absence of the green house gases in atmosphere, entire heat energy radiated from the earth's surface and objects on it, would escape out into the space and then the average temperature on earth would be –18°C (or 0°F) instead of being 15·5°C (or 60°F). On the other hand, if there is an increase in proportion of green house gases in atmosphere, the average temperature on earth will rise and it will be above 15·5°C (or 60°F).

Future projections : In the recent decades, it has been observed that the effective temperature of earth's surface has risen by 0·74 $\pm$ 0·18°C per decade for the last 50 years since 1900. The rate of increase is 2·5°C per decade (nearly three times since 1970) and since 2000, it is much more. So it is expected that by the end of this century, the earth's temperature will rise up to 64°C. The reason for this is the increase in the proportion of the green house gases present in the earth's atmosphere. Due to their increase, more heat radiations radiated from the earth's surface are trapped in its atompshere. It is believed that the human activities are responsible for the increase in the green house gas namely the carbon dioxide in the earth's atmosphere. The main human activities responsible for increase of the carbon dioxide gas are given below:

(i) The burning of fuels, deforestation, transportation and industrial production (particularly cement factories).

(ii) Increase of population (human beings emit nearly 32 giga tonnes of carbon dioxide each year).

(iii) Imbalance of carbon dioxide cycle (the ocean does not absorb full amount of carbon dioxide and the vegetables are not able to change all the carbon dioxide into oxygen).

The increase in the concentration of carbon dioxide due to above human activities is responsible for 60% increase in green house effect. Apart from this, rice cultivation, animal husbandry, natural gas exploration, burning of bio-mass in clearing of forests and leakage in natural gas pipe line has doubled the concentration of methane which is also responsible for the increase in green house effect.

Thus, the increase in green house gases in the atmosphere enhances the green house effect and this causes the *global warming*.

6.19 GLOBAL WARMING

Global warming means the increase in average effective temperature near the earth's surface due to an increase in the amount of green house gases in its atmosphere.

Our earth gets heated up due to absorption of visible and short wavelength infrared radiations received from the sun. The green house gases, namely the carbon dioxide, water vapours, methane and chlorofluorocarbons, trap the infrared radiations of long wavelength emitted from the earth's surface and thus keep the earth's surface warm at an average temperature of 15·5°C. It has been observed in recent decades that over a period of 50 years in the 20th century, the average temperature of earth's atmosphere has risen at a rate of 0·74 ± 0·18°C per decade. Now the rate of increase of temperature of earth's atmosphere is much more and it is expected that the earth's average temperature will reach to 64°C by the year 2100. *An increase in average temperature of the earth implies an increase in the amount of green house gases present in its atmosphere so that they could trap more heat radiated from the earth's surface*. It is believed that the human activities such as burning of fossil fuels, industrial growth, clearing of forests, use of automobiles *etc*., have played a significant role in increasing the green house gases (particularly carbon dioxide) in the earth atmosphere.

Cause of global warming : The cause of global warming is the increase in concentration of green house gases present in the atmosphere of earth due to human activities. The increase in different green house gases is as follows :

(i) The concentration of carbon dioxide has increased up to 25% due to industrial growth, combustion of fossil fuels, clearing of forests etc.

(ii) The concentration of methane has doubled due to agricultural sources such as rice cultivation and animal husbandry, natural gas exploration, burning of biomass, clearing of forests and leakage in natural gas pipe lines.

(iii) The concentration of chlorofluorocarbons has increased at a rate of 5% per year.

Thus increase in green house gases in atmosphere enhances the green house effect and hence causes global warming.

Impacts of global warming on life on the earth :

The increase in proportion of green house gases in the atmosphere has the following impacts on the life on earth :

(1) The variable changes in the climate in different parts of the world which has created difficulties and forced the people and animals to migrate from one place to the other.

(2) The change in blooming season of different plants.

(3) The change in regional climate which has an immediate effect on simple organisms and plants.

(4) The change in the world's ecology.

(5) The increase in the heat stroke deaths.

Future predictions : With the present rate of increase of green house effect and global warming, it is predicted that the average temperature of earth's surface will become 64°C by the end of the year 2100. Although it is not possible to make very accurate predictions on its impact for the future, but still looking at the changes in some natural phenomenon which we are facing now, following predictions can be made.

(1) Dislocation and disappearance of plant and animal species : At the present rate of increase of green house effect, it is expected that nearly 30% of the plant and animal species will vanish by the year 2050 and up to 70% by the end of the year 2100. This will disrupt ecosystem. The animals from the equatorial region will shift to higher latitude in search of ice and cold region. The absorption of carbon dioxide by ocean will cause acidification due to which marine species will migrate.

(2) Warming of ocean : The temperature of ocean water will increase due to which many species in the ocean will either die or they will disappear, while various other species which prefer warm water will increase tremendously.

(3) Melting of glacier : Due to global warming, the frozen tundra in Siberia has started melting. Greenland has experienced 32 glacial earth quakes in one year. The Arctic snow cover is expected to be ice-free by the end of September 2037. The global average sea level has risen at a rate of 3·1 mm per year. This rate of rise is expected to increase in future. It is also expected that the amount of oxygen dissolved in ocean will decrease which will have adverse effect on the marine life.

(4) Shift in farming region : In the near future, warming of nearly 3°C will result in poor yield in farms in low latitude regions and will increase the rise of malnutrition. The crop yield is expected to increase in middle and high latitude regions. Therefore farmers will have to shift their farming region from low latitude to high latitude.

(5) Increase in new diseases and heat related deaths : Due to global warming, many new diseases will emerge because bacteria can survive better in increased temperature and they can multiply faster. It will extend the distribution of mosquitoes due to increase in humidity levels and their frequent growth in warmer atmosphere. This will result in increase of many new diseases. Apart from it, the deaths due to heat stroke will also increase.

(6) Change in regional climate : It is expected that the warming over land will increase and it will be maximum at high northern latitudes while minimum over the southern ocean. The frequency of hot extremes, heat waves and heavy precipitation will also increase.

(7) Variable changes in the climate : The variable changes in the climate will result in increase in the number of people suffering from death diseases and injuries from floods, storms and droughts.

(8) Increase in cost of air conditioning : Due to warming effect, the cost of air conditioning will increase as it will consume more electric energy.

(9) Change in sea level : Due to melting of ice, the area of sea ice around both the poles is shrinking. It is expected that in the next 50 years, the ice at both the poles will melt completely and therefore the sea level will rise. Buildings and roads in the coastal areas will get flooded and they could suffer damage from hurricans and tropical storms.

6.20 WAYS TO MINIMISE THE IMPACT OF GLOBAL WARMING

To minimise the impact of global warming, following *three* main measures must be taken : (1) Technological measures, (2) Economic measures and (3) Policy measures. These measures are inter-related and must be taken simultaneously.

(1) Technological measures

The economic growth and population growth, each increases consumption of fuel and hence both are responsible for the release of green house gases. We need to check them and use the following *three* technological measures :

(a) Use of renewable sources of energy to generate electricity in place of generating electricity from the fossil fuels based power plants, (b) Change of transportation vehicles, and (c) Use of bio-char stoves for cooking.

(a) Use of renewable sources of energy for generation of electricity in place of electricity from the fossil fuel based power plants : The fossil fuel based power plants are the main source of generation of the green house gases. They produce nearly 21·3% of the total green house gases. Therefore alternate energy sources such as wind energy, solar energy, tidal energy, geo thermal energy, etc. must be used to generate electricity in place of fossil fuel based power plants. *The fossil fuel based power plants must be banned.*

(b) Change of transportation vehicles : Vehicles such as lorry, truck etc. that are presently in use for transportation are run by the internal combustion engine and they contribute nearly 14% of the total green house gas emission. Such vehicles must be switched to battery operated vehicles which will reduce carbon dioxide emission drastically. For charging the battery, electricity generated from renewable sources must be used. Further the vehicles must be used at their full capacity and the size of vehicles must be reduced.

(c) Use of bio-char stoves for cooking : In developing countries, bio-mass is mostly used for cooking which also contributes significantly in the increase of green house gases. For burning the bio-mass, new technology must be used to burn it in absence of air in a specially constructed stove known as *bio-char stove*. It will release the smokeless combustible gases methane and hydrogen, leaving a charcoal residue which can be buried in soil.

(2) Economic measures

The industrial growth and deforestation for population growth have caused the increase in green house effect. To check them, following *two* economic measures are needed : *(a) Reforestation and sustainable use of land, and (b) Industries to pay carbon tax.*

(a) Reforestation and sustainable use of land : In developing countries, the pressure of population and industrial growth has resulted in unsustainable agricultural practices which are responsible for 90% of deforestation. These countries must be asked to reforest and maintain forest habitats. Their loss must be verified by satellite imaging before compensating them by the international agencies.

(b) Industries to pay carbon tax : Since industries emit carbon dioxide to a good extent, so to check them, they must be asked to pay carbon tax. This tax can be calculated on the basis of carbon emission from the industry, number of employee hour and turn over of the industry. This will encourage the industry to use the energy efficient offices and to avoid the travelling of its employees by having tele-conferencing.

(3) Policy measures

To check global warming, Government must take the following *two* policy measures : *(a) Educating children to live sustainable life style, and (b) Controlling population through family planning, welfare reforms and the empowerment of women.*

(a) Educating children to live sustainable life style : We need to educate children that genuine happiness lies in a less competitive and more cooperative society. Consuming more and buying more must not be the aim of life. For a sustainable life, we must make full use of what we have. The materialistic gain gives a temporary pleasure.

(b) Controlling population through family planning, welfare reforms and the empowerment of women : The world population is expected to increase from 7·1 billion in the year 2012 to 9·15 billion by the year 2050 with most of the growth taking place in the developing countries. This needs to be controlled. Population growth can be controlled through various measures such as (i) free and easy access to family planning, (ii) welfare provisions to encourage smaller families, and (iii) the empowerment of women through education and freedom to choose their future career (because the educated women are more conscious about family planning due to their career commitments).

Recently in 'the 21st yearly 2015 United Nations Climate Change conference CUP21/CMP11' held in Paris from November 30 to December 12, 2015 each nation has expressed a deep concern on the present rate of increase of green house gases and it is committed to limit the global warming to below 2·0°C compared to pre-industrial level by the year 2100 for which a goal of zero carbon emission is to be achieved between 2030 to 2050.

EXERCISE 6(D)

1. What do you mean by green house effect ?
2. Name *three* green house gases.
3. Which of the following solar radiations pass through the atmosphere of the earth :
   X-rays, ultraviolet rays, visible light rays, infrared radiation.
   Ans. Visible light rays and infrared radiation
4. Name the radiation which are absorbed by the green house gases.
   Ans. Infrared radiation of long wavelength
5. What results in the increase of carbon dioxide contents of earth's atmosphere ?
6. What would have been the temperature of earth's atmosphere in absence of green house gases in it ?

7. State the effect of green house gases on the temperature of earth's atmosphere.
8. What do you mean by global warming ?
9. What causes the rise in atmospheric temperature ?
10. State the cause of increase of green house effect.
11. What will be the effect of global warming at the poles ?
12. State the effect of global warming in coastal regions.
13. How will global warming affect the sea level.
14. How will global warming affect the agriculture ?
15. State *two* ways to minimise the impact of global warming.
16. What is carbon tax ? Who will pay it ?

Multiple choice type :

1. The green house gas is :
   (a) oxygen (b) nitrogen
   (c) chlorine (d) carbon dioxide.
   Ans. (d) carbon dioxide
2. The increase of carbon dioxide gas in atmosphere will cause :
   (a) decrease in temperature
   (b) increase in temperature
   (c) no change in temperature
   (d) increase in humidity.
   Ans. (b) increase in temperature
3. Without green house effect, the average temperature of earth's surface would have been :
   (a) –18°C (b) 33°C
   (c) 0°C (d) 15°C
   Ans. (a) –18°C
4. The global warming has resulted in :
   (a) the increase in yield of crops
   (b) the decrease in sea levels
   (c) the decrease in human deaths
   (d) the increase in sea levels.
   Ans. (d) the increase in sea levels.

7 REFLECTION OF LIGHT

Syllabus :

(i) *Reflection of light; images formed by a pair of parallel and perpendicular plane mirrors.*
Scope – Laws of reflection; experimental verification; characteristics of images formed in a pair of mirrors (a) parallel and (b) perpendicular to each other; uses of plane mirrors.

(ii) *Spherical mirrors; characteristics of image formed by these mirrors (only simple direct ray diagrams are required).*
Scope – Brief introduction to spherical mirrors-concave and convex mirrors, centre and radius of curvature, pole and principal axis, focus and focal length, location of images from ray diagram for various positions of a small linear object on the principal axis of concave and convex mirrors; characteristics of images, $f = R/2$ (without proof); sign convention and direct numerical problems using the mirror formulae are included (Derivation of formula not required). Uses of spherical mirrors. *Scale drawing or graphical representation of ray diagram not required.*

(A) LAWS OF REFLECTION & FORMATION OF IMAGE BY A PLANE MIRROR

7.1 REFLECTION OF LIGHT

When a beam of light strikes a surface, a part of it returns into the same medium. The part of light which is returned into the same medium is called the *reflected light*. Thus

The return of light into the same medium after striking a surface is called reflection.

The remaining part of light is either absorbed if the surface on which the light strikes is opaque or it is partly transmitted and partly absorbed if the surface is transparent.

It is the reflection of light which enables us to see the different objects around us. An object is seen when light from it enters our eyes. The luminous bodies which emit light by themselves are directly seen, but the non-luminous objects are seen only when they reflect the light incident on them and the reflected light reaches our eyes.

Different surfaces reflect light to different extent. A highly polished and silvered surface, such as a *plane mirror*, reflects almost the entire light falling on it.*

A plane mirror is made from a few mm thick glass plate. One surface of glass plate is polished to a high degree of smoothness. This forms the front surface of mirror and the other (or back) surface is silvered (*i.e.*, silver, mercury or some suitable material is deposited over it). The silvered surface is further coated with some opaque material so as to protect the silvering on it. The two surfaces of plane mirror are shown in Fig. 7.1. Light enters from the side of polished surface and is strongly reflected from the silvered surface. The coating serves as an opaque surface and it does not reflect the light.

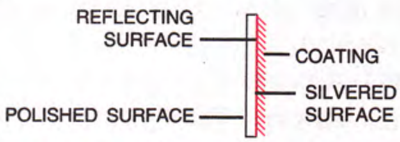


Fig. 7.1 Representation of a plane mirror

Kinds of reflection : There are the following *two* kinds of reflection :

(i) Regular reflection, and
(ii) Irregular reflection.

(i) Regular reflection : *Regular reflection occurs when a beam of light falls on a smooth and polished surface,* such as a plane mirror. In

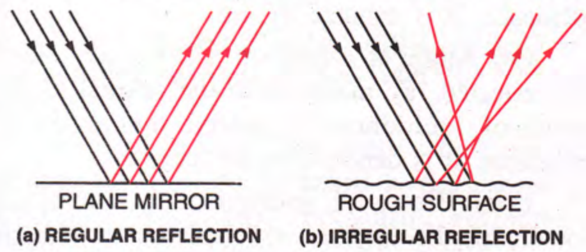


Fig. 7.2 Regular and irregular reflection

* A plane mirror does not reflect cent percent light falling on it.

Fig. 7.2(a), a parallel beam of light is incident on a plane mirror. The reflected beam is also parallel and it is in a fixed direction. It can be seen only from a particular direction.

(ii) Irregular reflection : *Irregular reflection occurs when a beam of light falls on a rough surface* such as the wall of a room, the page of a book or any other object. Although the wall of a room or the page of a book appears to be smooth, but actually it is quite uneven having many small projections over it. In Fig. 7.2(b) *light rays fall at different points on a rough surface and each ray gets reflected from it obeying the laws of reflection of light. Due to uneven surface, at different points, light rays get reflected in different directions and give rise to the diffused or irregular reflection.* As a result, the reflected light spreads over a wide area and it does not follow a particular direction. Thus the reflected light can be seen from anywhere.

It is the diffused light obtained by reflection from various uneven surfaces which enables us to see the objects around us.

7.2 SOME TERMS RELATED WITH REFLECTION

(i) Incident ray : The light ray striking a reflecting surface is called the incident ray.

(ii) Point of incidence : The point at which the incident ray strikes the reflecting surface, is called the point of incidence.

(iii) Reflected ray : The light ray obtained after reflection from the surface, in the same medium in which the incident ray is travelling, is called the reflected ray.

(iv) Normal : The perpendicular drawn to the surface at the point of incidence, is called the normal.

(v) Angle of incidence : The angle which the incident ray makes with the normal at the point of incidence, is called the angle of incidence. It is denoted by the letter *i*.

(vi) Angle of reflection : The angle which the reflected ray makes with the normal at the point of incidence, is called the angle of reflection. It is denoted by the letter *r*.

(vii) Plane of incidence : The plane containing the incident ray and the normal, is called the plane of incidence.

(viii) Plane of reflection : The plane containing the reflected ray and the normal, is called the plane of reflection.

In Fig. 7.3, MM_1 is a plane reflecting surface (say, a plane mirror) kept perpendicular to the plane of paper. A light ray is incident in the direction AO at the point O on mirror. It is reflected along the direction OB. Thus, AO is the *incident ray*, O is the point of incidence and OB is the *reflected ray*.

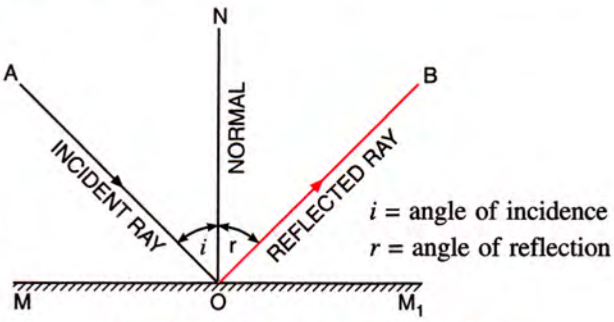


Fig. 7.3 Reflection at a plane surface

Let ON be the *normal* (or perpendicular) drawn to the surface MM_1 at the point O. The angle i (= $\angle AON$), which the incident ray makes with the normal, is the *angle of incidence* and the angle r (= $\angle BON$), which the reflected ray makes with the normal, is the *angle of reflection*. The plane of paper is the *plane of incidence*.

7.3 LAWS OF REFLECTION

A light ray obeys the following *two* laws for reflection from a surface, which are called the *laws of reflection*.

(1) *The angle of incidence i is equal to the angle of reflection r (i.e., $\angle i = \angle r$).*

In Fig. 7.3, $\angle AON = \angle BON$ ...(7.1)

(2) *The incident ray, the reflected ray and the normal at the point of incidence, lie in the same plane.*

In Fig. 7.3, *AO, ON* and *OB* are in one plane (*i.e.*, the plane of paper).

Reflection of a ray of light normally incident on a plane mirror

For a ray incident normally on a plane mirror, the angle of incidence $i = 0°$, therefore the angle of reflection $r = 0°$. Thus, a ray of light AO incident

normally on a mirror is reflected along the same path *OA* *i.e.*, it retraces its path as shown in Fig. 7.4.

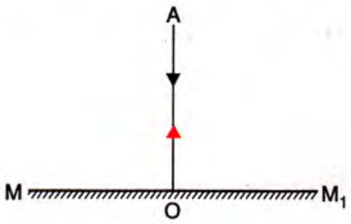


Fig. 7.4 Reflection of a ray of light normally incident on a plane mirror

7.4 EXPERIMENTAL VERIFICATION OF THE LAWS OF REFLECTION

Experiment : Fix a sheet of white paper on a drawing board and draw a line MM_1 as shown in Fig. 7.5. On this line, take a point *O* nearly at the middle of it and draw a line *OA* such that $\angle MOA$ is less than 90° (say, $\angle MOA = 60°$). Then draw a normal *ON* on line MM_1 at the point *O*, and place a small plane mirror vertical by means of a stand with its silvered surface on the line MM_1.

Now fix two pins *P* and *Q* at some distance (≈ 5 cm) apart vertically on line *OA*, on the board. Keeping eye on other side of normal (*but on the same side of mirror*), see clearly the images *P′* and *Q′* of the pins *P* and *Q*. Now fix a pin *R* such that it is in line with the images *P′* and *Q′* as observed in the mirror. Now fix one more pin *S* such that the pin *S* is in line with the pin *R* as well as the images *P′* and *Q′* of pins *P* and *Q*.

Draw small circles on paper around the position of pins as shown in Fig. 7.5. Remove the pins and draw a line *OB* joining the point *O* to the pin points *S* and *R*.

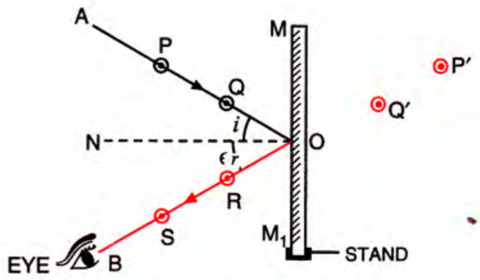


Fig. 7.5 Verification of laws of reflection

In Fig. 7.5, *AO is the incident ray, OB is the reflected ray,* $\angle AON = i$ *is the angle of incidence* and $\angle BON = r$ *is the angle of reflection*. The angles *AON* and *BON* are measured and recorded in the observation table.

The experiment is repeated for the $\angle MOA$ equal to 50°, 40° and 30°.

Observations

S. No.	Angle of incidence $i = \angle AON$ (in degree)	Angle of reflection $r = \angle BON$ (in degree)
1.	30	30
2.	40	40
3.	50	50
4.	60	60

From the above observation table, we find that in each case, angle of incidence is equal to the angle of reflection. *This verifies the first law of reflection.*

The experiment is being performed on a flat drawing board, with mirror normal to the plane of board on which white sheet of paper is being fixed. Since the lower tips of all the four pins lie on the same plane (*i.e.*, the plane of paper), therefore the incident ray, the reflected ray and the normal at the point of incidence, all lie in one plane. *This verifies the second law of reflection.*

7.5 FORMATION OF IMAGE BY REFLECTION

From each point of an illuminated object, rays of light travel in all directions. To find the position of image of an object formed by a mirror after reflection, we need to consider at least *two* rays of light incident on the mirror from a point of object. Each incident ray gets reflected obeying the laws of reflection. The point where the two reflected rays actually meet or they appear to meet (when produced backwards), gives the position of image of that point of object. Thus we can obtain the positions of image of different points of the object. By joining these points, complete image of the object can be obtained.

Types of image : The image can be of *two* types : (a) real image, and (b) virtual image.

(a) Real image : The image which can be obtained on a screen, is called a *real image*. It is formed when light rays after reflection *actually intersect*. It is *inverted*. *For example*,

for a distant object, the image formed by a concave mirror is real.

(b) Virtual image : The image which cannot be obtained on a screen, is called a *virtual image*. It is formed when light rays after reflection *do not* actually intersect, but they appear to diverge from the image*. Geometrically, they intersect when they are produced backwards. It is *erect*. *For example*, the image of an object formed by a plane mirror or by a convex mirror is virtual.

Distinction between a real and virtual image

Real image	Virtual image
1. A real image is formed due to actual intersection of the reflected rays.	1. A virtual image is formed when the reflected rays meet if they are produced backwards
2. A real image can be obtained on a screen.	2. A virtual image can not be obtained on a screen.
3. A real image is inverted with respect to the object *Example* : The image of a distant object formed by a concave mirror	3. A virtual image is erect with respect to the object. *Example* : The image of an object formed by a plane mirror or by a convex mirror.

7.6 IMAGE OF A POINT OBJECT FORMED BY A PLANE MIRROR

In Fig. 7.6, let MM_1 be a plane mirror in front of which a point object O is placed. From the object O, rays of light travel in all directions. To show the formation of image by the plane mirror, we consider *two* rays from the object O which fall on mirror MM_1. Let OA and OB be two rays incident from the object O which get reflected from the mirror MM_1 in directions AC and BD respectively such that $\angle CAN_1 = \angle OAN_1$ and $\angle DBN_2 = \angle OBN_2$. Here AN_1 and BN_2 are the normals at the points A and B.

When seen from a position between C and D, the rays between C and D appear to come from some point I behind the mirror. The point I is the image of the object O. To locate the position of I, reflected rays AC and BD are produced backwards and the point where they meet, gives the position of image I. The image is *virtual* because the reflected rays AC and BD do not actually meet at I, but to our eye they appear to come from the point I.

7.7 IMAGE OF AN EXTENDED OBJECT FORMED BY A PLANE MIRROR

In Fig. 7.7, let MM_1 be a plane mirror in front of which an extended object AB is placed. From all points of the object, light rays travel in all directions. We consider only *two* rays incident on the plane mirror from the end points A and B of the object. Let AP and AQ be the *two* rays incident on the mirror from the point A of the object which get reflected from the mirror as PP' and QQ' respectively. These reflected rays when produced backwards, meet at a point A'. Thus A' is the virtual image of point A. Similarly, from the point B of object, BR and BS be the *two* incident rays on the mirror which are reflected as RR' and SS' respectively. The reflected rays RR' and SS' meet at a point B' when produced backwards. Thus, B' is the virtual image of point B. Similarly, for all other points of the object AB, virtual images are formed between A' and B'. Thus $A'B'$ is the virtual image

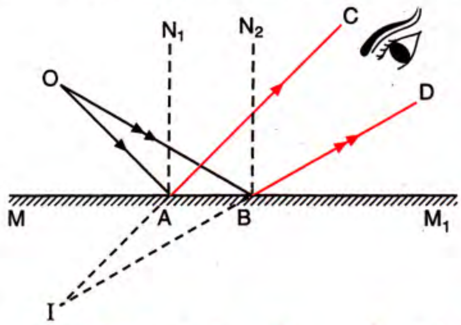


Fig. 7.6 Formation of image of a point object by a plane mirror

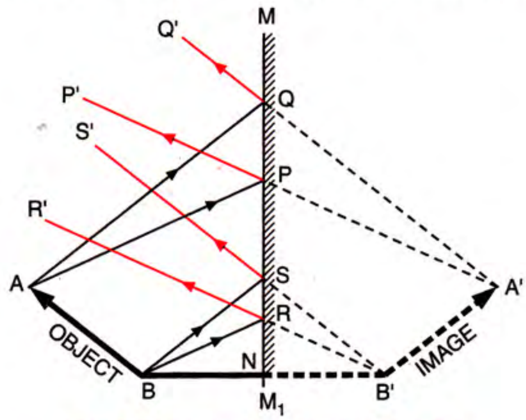


Fig. 7.7 Image of an extended object formed by a plane mirror

* When these diverged rays enter our eye, they converge to form an image on our retina and the image is seen by us.

of the object AB. *It is erect and of size equal to that of the object. The normal distance of each point of image behind the mirror is same as the normal distance of the corresponding object point in front of the mirror (i.e., BN = B'N).*

7.8 POSITION OF IMAGE

The image I is as far behind the mirror as the object O is in front of it i.e., the perpendicular distance of image from the mirror is equal to the perpendicular distance of object from the mirror.

Proof : Fig. 7.8 shows the formation of image of a point object O by a plane mirror MM_1. A ray OF incident normally on the mirror gets reflected by the mirror along the same path (*i.e.*, along FO), since $\angle i = 0°$, therefore $\angle r = 0°$. The other incident ray OA gets reflected along AC, such that $\angle OAN = \angle NAC$ where AN is the normal drawn at the point A on mirror MM_1. The reflected rays FO and AC meet at a point I when they are produced backwards. The point I is the virtual image of the point object O. We are to prove that $IF = OF$.

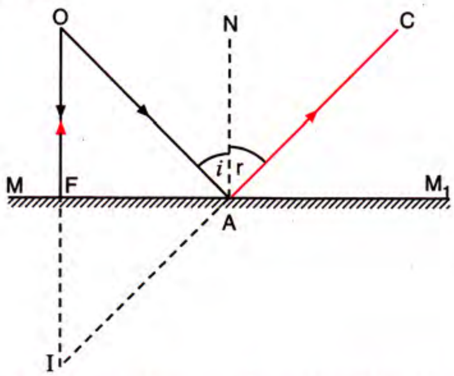


Fig. 7.8 Formation of image of a point object due to reflection at a plane mirror

For the incident ray OA reflected as AC,

$\angle OAN$ = angle of incidence i

$\angle CAN$ = angle of reflection r

By the law of reflection,

angle of incidence = angle of reflection

or $\angle OAN = \angle CAN$ ...(7.2)

But $\angle OAN = \angle AOF$ (Alternate angles)

and $\angle CAN = \angle AIF$ (Corresponding angles)

$\therefore \angle AOF = \angle AIF$ ...(7.3)

Now consider the triangles AOF and AIF

$\angle AOF = \angle AIF$

$\angle AFO = \angle AFI$ (= 90°)

and FA is the common side.

Therefore, the triangles AOF and AIF are congruent.

Hence, $OF = IF$ .... (7.4)

Since OF is the normal drawn from the object O on the mirror, so the normal distance of the object from the mirror is equal to the normal distance of image from the mirror. Thus,

The image is situated on the normal drawn from the object on the mirror and it is as far behind the mirror as the object is in front of it.

7.9 LATERAL INVERSION

In our daily experience while looking in a mirror, we notice that a ring on the finger of our left hand appears to be in the finger of the *right hand of our image* as shown in Fig. 7.9. Similarly, the pocket on the left appears to be on the right in the image. This interchange of the left and right sides is called the *lateral inversion*. Thus,

The interchange of the left and right sides in the image of an object in a plane mirror is called lateral inversion.

Fig. 7.9 Image of a ring on the finger of left hand in a plane mirror

Fig. 7.10 shows the image formation of a letter P in a plane mirror. The letter **P** appears in a plane mirror as **ꟼ**. Similarly, the letter **F** will appear as **ꟻ**.

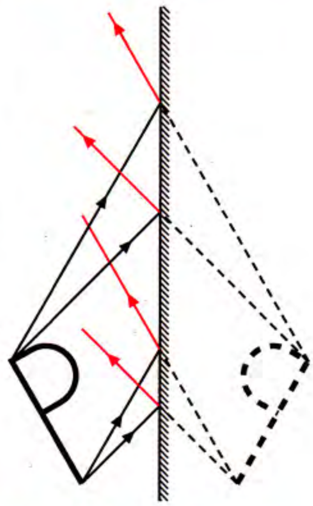


Fig. 7.10 Lateral inversion

Note : (1) The lateral inversion produced by a plane mirror is similar to the inversion that occurs on a blotting paper used to dry ink while writing.

The individual letter obtained on the blotting paper cannot be read directly, but it can be read by seeing its image in a plane mirror.

(2) The lateral inversion of letters such as A, H, I, M, O, T, U, V, W, X and Y is not noticeable since their image remains unchanged (because each of these letters has a symmetry about a vertical line passing through the mid point of the letter).

(3) It is because of the lateral inversion that it becomes difficult to read the text of a page from its image formed by a plane mirror. But one can easily read the text written in '*laterally inverted letters*' formed by seeing its image in a plane mirror. It is why the letters on the front of an ambulance are written laterally inverted like ƎƆИA⅃UBMA, so that the driver of the vehicle moving ahead of the ambulance reads the word laterally inverted as AMBULANCE, in his rear view mirror, and gives side to pass the ambulance first.

(4) The image formed by a spherical mirror is also laterally inverted.

7.10 CHARACTERISTICS OF THE IMAGE FORMED BY A PLANE MIRROR

The image formed by a plane mirror has the following characteristics :

(i) upright (or erect), *(ii) virtual,*
(iii) of same size as the object, and
(iv) laterally inverted.

The location of the image is given by the fact that, *the image is situated at the same perpendicular distance behind the mirror as the object is in front of it.*

Note : If the object is shifted by a distance d towards the mirror, the image will also shift by the same distance d towards the mirror *i.e.,* the separation between the object and image will decrease by $2d$. Similarly, if an object moves with a speed v towards (or away) from a mirror, the *image to him* will appear to move with a speed $2v$ towards (or away from) him.

Example : A boy standing at a distance 5 m away from a plane mirror at A, finds his image at a distance 10 m from him at A'. Now if he moves to the position B by a distance 2 m still farther away from the mirror, his distance from the mirror will become 7 m and then to him, his image B' will appear to be at a distance 14 m from him as shown in Fig. 7.11.

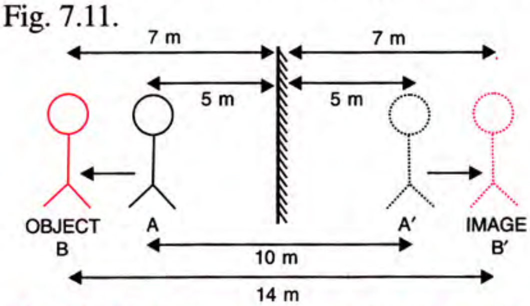


Fig. 7.11 Displacement of image in a plane mirror when the object moves

EXAMPLES

1. In a dark room, a parallel beam of light falls on a plane mirror and another parallel beam of light falls on a white wall. The light reflected by the mirror can be seen only in a certain direction, but the reflected light from the wall can be seen from anywhere. Give reason.

The plane mirror has a plane smooth reflecting surface, so regular reflection takes place and the reflected light goes in a fixed direction. Therefore, the reflected light can be seen only in a certain direction.

On the other hand, the wall is a rough surface so irregular reflection takes place, and reflected light gets diffused in all directions. Therefore, the reflected light from the wall can be seen from anywhere.

2. Complete the diagram in Fig. 7.12 to form the image $A'B'$ of the object AB by the plane mirror MM_1. State in words how have you completed the diagram. Measure the perpendicular distance of the points A and B of the object from the mirror and also the perpendicular distance of the points A' and B' of the image from the mirror and state how are they related.

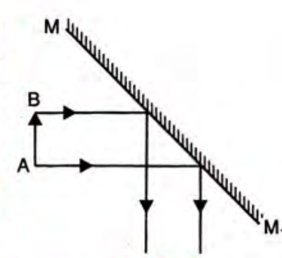


Fig. 7.12

The completed diagram is shown in Fig. 7.13.

To complete the diagram, rays AP and BQ are made incident normally on the mirror MM_1 from the points A and B of the object, which retraces

their path after reflection. The other rays AP' and BQ' get reflected from the plane mirror obeying the laws of reflection Each of the reflected ray is produced backwards to get the image $A'B'$.

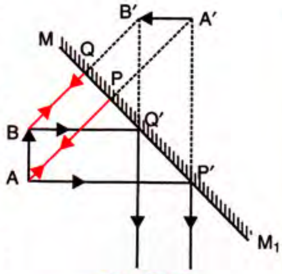


Fig. 7.13

Perpendicular distance AP of A from the mirror = **1·5 cm** = Perpendicular distance $A'P$ of A' from the mirror.

Perpendicular distance BQ of B from the mirror = **1·1 cm** = Perpendicular distance $B'Q$ of B' from the mirror.

3. An object is at a distance 25 cm in front of a plane mirror. The mirror is shifted 5 cm away from the object. Find : (i) the new distance between the object and its image, and (ii) the distance between the two positions of the image.

Fig. 7.14 shows the images B and B' the object A, by the mirror in its initial and new postions.

Initially, the distance of the object A in front of plane mirror M is $AM = 25$ cm, therefore the image

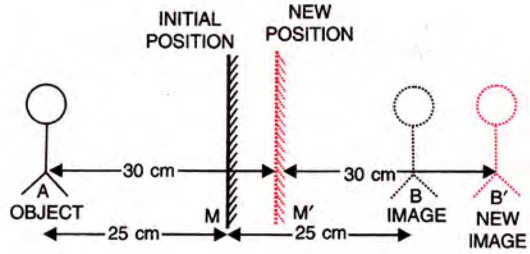


Fig. 7.14

B is at a distance $MB = 25$ cm from the mirror M behind it. Distance between the object A and its image $B = 25$ cm + 25 cm = 50 cm.

On shifting the mirror by 5 cm away from the object, the new distance of object A from the mirror M' becomes $AM' = 25 + 5 = 30$ cm. The new image B' is now at a distance $M'B' = 30$ cm behind the mirror M'. Hence

(i) The new distance AB' between the object A and the image B' = 30 cm + 30 cm = **60 cm**.

(ii) Taking the position of the object A as reference point, the distance between the two positions of the image, BB' = new distance of image from the object, AB' – initial distance of image from the object, AB = 60 – 50 = **10 cm**.

EXERCISE 7(A)

1. What do you mean by reflection of light ?
2. State which surface of a plane mirror reflects most of the light incident on it : the front smooth surface or the back silvered surface.

   Ans. Back silvered surface.
3. Explain the following terms :
   (a) plane mirror, (b) incident ray,
   (c) reflected ray, (d) angle of incidence, and
   (e) angle of reflection.
   Draw diagram/diagrams to show them.
4. With the help of diagrams, explain the difference between the regular and irregular reflection.
5. Differentiate between the reflection of light from a plane mirror and that from a plane sheet of paper.
6. State the *two* laws of reflection of light.
7. State the laws of reflection and describe an experiment to verify them.
8. A light ray is incident normally on a plane mirror.
   (a) What is its angle of incidence ?
   (b) What is the direction of reflected ray ? Show it on a diagram.

   Ans. (a) 0°, (b) same as incident ray
9. Draw a diagram to show the reflection of a ray of light by a plane mirror. In the diagram, label the incident ray, the reflected ray, the normal, the angle of incidence and the angle of reflection.
10. Fig. 7.15 shows an incident ray AO and the normal ON on a plane mirror. The angle which the incident ray AO makes with the mirror is 30°. (a) Find the angle of incidence. (b) Draw the reflected ray and then find the angle between the incident and reflected rays.

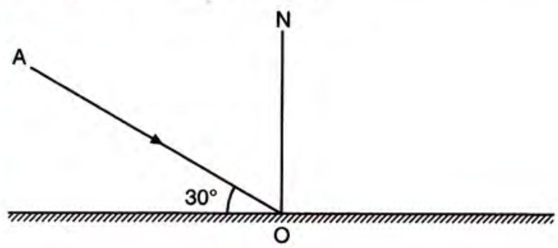


Fig. 7.15

Ans. (a) 60°, (b)120°

11. The diagram in Fig. 7.16 shows a point object P in front of a plane mirror MM_1.

(a) Complete the diagram by taking *two* rays from the point P to show the formation of its image.

(b) In the diagram, mark the position of eye to see the image.

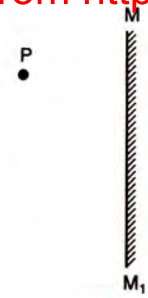


Fig. 7.16

(c) Is the image formed real or virtual ? Explain why ?

Ans. (c) Virtual because the reflected rays meet only when they are produced backwards

12. The diagram below in Fig. 7.17 shows an object XY in front of a plane mirror MM_1. Draw on the diagram, path of *two* rays from each point X and Y of the object to show the formation of its image.

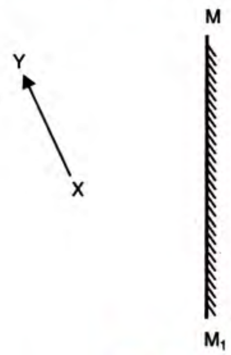


Fig. 7.17

13. (a) Write *three* characteristics of the image formed by a plane mirror ?

(b) How is the position of image related to the position of the object ?

14. Differentiate between a real and a virtual image.

15. What is meant by lateral inversion of an image in a plane mirror ? Explain it with the help of a ray diagram.

16. The letters on the front of an ambulance are written laterally inverted like ƎƆИA⅃UꓭMA.Give reason.

17. Why is it difficult to read the image of the text of a page formed due to reflection by a plane mirror ? **Ans.** Due to lateral inversion.

Multiple choice type :

1. According to the law of reflection :
   (a) i/r = constant
   (b) $\sin i/\sin r$ = constant
   (c) $i + r$ = constant
   (d) $i = r$ **Ans.** (d) $i = r$

2. The image formed by a plane mirror is :
   (a) erect and diminished
   (b) erect and enlarged
   (c) inverted and of same size
   (d) erect and of same size.
   Ans. (d) erect and of same size

3. The image formed by a plane mirror is :
   (a) real
   (b) virtual
   (c) virtual with lateral inversion
   (d) real with lateral inversion.
   Ans. (c) virtual with lateral inversion

Numericals :

1. A ray is incident on a plane mirror. Its reflected ray is perpendicular to the incident ray. Find the angle of incidence. **Ans.** 45°

2. A man standing in front of a plane mirror finds his image at a distance 6 metre from himself. What is the distance of man from the mirror ? **Ans.** 3 m

3. An insect is sitting in front of a plane mirror at a distance 1 m from it.
   (a) Where is the image of the insect formed ?
   (b) What is the distance between the insect and its image ?
   Ans. (a) 1 m behind the mirror (b) 2 m

4. An object is kept at 60 cm in front of a plane mirror. If the mirror is now moved 25 cm away from the object, how does the image shift from its previous position ?
   Ans. 50 cm away.

5. An optician while testing the eyes of a patient keeps a chart of letters 3 m behind the patient and asks him to see the letters on the image of chart formed in a plane mirror kept at distance 2 m in front of him. At what distance is the chart seen by the patient ? **Ans.** 7 m.

(B) IMAGES FORMED IN A PAIR OF MIRRORS

7.11 IMAGES FORMED IN TWO INCLINED MIRRORS

For an object kept in between the two inclined plane mirrors, we get many images of the object. This is because the light rays after reflection from one mirror fall on the other mirror. In other words, the image formed by one mirror acts as an object for the other mirror. This continues till no more reflection can occur on any mirror.

The object and the images formed by the two inclined mirrors lie on the circumference of a circle whose centre lies at the point of intersection of the two mirrors and radius is equal to the distance of object from the point of intersection.

The number of images formed depends on the angle θ° between the two mirrors. Following two cases are possible :

Case (1) : If angle θ° between the mirrors is such that $n = \frac{360°}{\theta°}$ is odd,

(i) the number of images is *n*, when the object is placed *asymmetrically* between the mirrors.

(ii) the number of images is $n - 1$, when the object is placed *symmetrically* (*i.e.*, on the bisector of the angle) between the mirrors.

Example : If θ is 72°, then $n = \frac{360°}{72°} = 5$. So images formed will be $n = 5$ for the object placed asymmetrically between the mirrors and images formed will be $(n - 1) = 4$, if the object is placed symmetrically (on the bisector) between the mirrors because two images now overlap.

Case (2) : If $n = \frac{360°}{\theta°}$ is even, the number of images is always $n - 1$ for all positions of object in between the mirrors.

Example : If the angle between two mirrors is 60°, $n = \frac{360°}{60°} = 6$, the number of images is $(n - 1) = 5$, *i.e.* five images will be formed for all positions of the object in between the mirrors..

We shall now consider image formation in *two* special cases :

(a) When the two mirrors are parallel to each other.

(b) When the two mirrors are perpendicular to each other.

7.12 IMAGES FORMED IN A PAIR OF MIRRORS PLACED PARALLEL TO EACH OTHER

When two mirrors are kept parallel to each other, *i.e.*, (θ = 0°), then $n = \frac{360°}{\theta°} = \frac{360°}{0°} = \infty$ (infinite), so the number of images of an object kept in between the two parallel mirrors will be infinite. Thus

For two mirrors kept parallel to each other, an infinite number of images are formed for an object kept in between them.

In Fig. 7.18, *AM* and BM_1 are the two plane mirrors placed parallel to each other. An object *P* is placed in between them. The image of *P* formed by reflection from mirror *AM* is I_1 and by reflection from mirror BM_1 is *I'*. The ray diagram for the formation of image *I'* is not shown in Fig. 7.18. Now I_1 acts as a virtual object for mirror BM_1 and the image I_2 is formed. Similarly, *I'* acts as the virtual object for mirror *AM* and the image *I''* is formed. In this manner, many images are formed. But the brightness of the remote images keeps on decreasing because at each reflection, some light is absorbed, thus not more than few images are seen. Fig. 7.18 shows the ray diagram for the formation of one set of images only (*i.e.*, I_1, I_2,

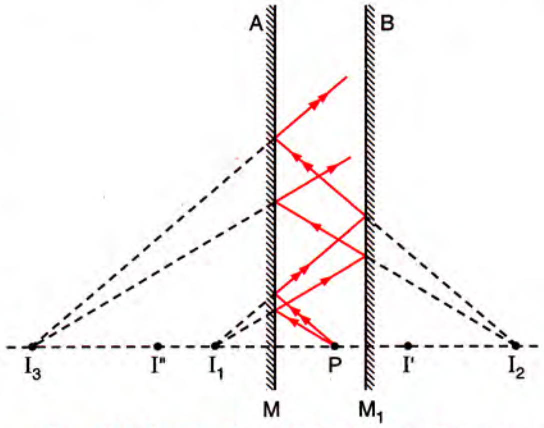


Fig. 7.18 Images formed in two parallel mirrors

I_3,...). The formation of other set of images (*i.e.*, I', I'', ...) can similarly be obtained. All images lie on the perpendicular drawn from the base of object on the mirrors.

Use : In a showroom and in a barber's shop, mirrors are arranged in this manner.

Note : *A thick plane mirror also forms a multiple number of images* due to multiple reflections within the glass from front surface and back reflecting surface. Out of these, the second image formed due to reflection from the back reflecting surface is brightest.

7.13 IMAGES FORMED BY TWO MIRRORS PLACED PERPENDICULAR TO EACH OTHER

When two mirrors are kept perpendicular to each other, *i.e.*, $\theta = 90°$, then

$$n = \frac{360°}{\theta°} = \frac{360°}{90°} = 4$$

$\therefore$ for an object placed in between the two perpendicular mirrors, the number of images formed will be $n - 1 = 3$. Thus

> *For two mirrors kept perpendicular to each other, three images are formed for an object kept in between them.*

In Fig. 7.19, AO and OB are the two plane mirrors kept mutually perpendicular to each other. Let P be an object in between the two mirrors. The image of object P formed by reflection from the mirror OB is P_2 and by reflection from the mirror OA is P_1. Fig. 7.19 shows ray diagram for the formation of image P_2 only. Now the image P_2 acts as the virtual object for the mirror OA since rays after reflection from mirror OB fall on the mirror OA. For this, the image formed by mirror OA is P_3. Similarly, P_1 acts as the virtual object for the mirror OB since the rays after reflection from the mirror OA fall on mirror OB (they are not shown in figure). For this, the image formed by mirror OB is P_4 which is at the same point as P_3 (*i.e.*, the image P_4 of P_1 in mirror OB overlaps with the image P_3 of P_2 in mirror OA). *As such, three images of object are formed in this case.* In Fig. 7.19, ray diagram for the formation of images P_2 and P_3 is shown. Similarly, we can draw the ray diagram for the formation of images P_1 and P_4. Geometrically it can be seen that the images P_1, P_2, P_3 and the object P, all lie on a circle whose centre is at O (the point of intersection of the two mirrors OA and OB) and radius is OP.

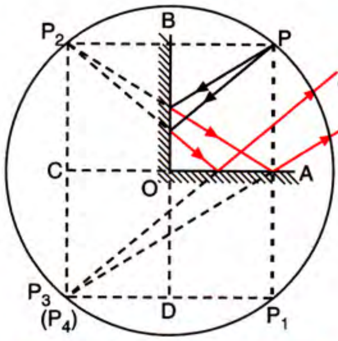


Fig. 7.19 Images formed in two perpendicular mirrors

7.14 USES OF PLANE MIRROR

The plane mirrors find wide applications in our daily life. Some of the applications of a plane mirror are given below.

(1) The most common and wide use is as a looking glass.

(2) In the optician's room to increase the effective length of the room. It is done by keeping a plane mirror on the front wall and the sign board on the opposite wall, just behind the patient. For the patient, the sign board is at nearly double the length of the room.

(3) In the barber's shop for seeing the hairs at the back of head. Here two mirrors facing each other are fixed on the opposite walls at the front and back of the viewer.

(4) In a periscope, two parallel plane mirrors each inclined at 45° with the vertical walls are placed facing each other.

(5) In a kaleidoscope, three plane mirrors inclined with each other at 60° are used. If small coloured bangle pieces are kept between the mirrors, beautiful hexagonal patterns are seen on rotating the tube.

(6) In solar heating devices such as solar cooker, solar water heater, etc., a plane mirror is used to reflect the incident light rays from sun on the substance to be heated.

EXERCISE 7(B)

1. Two plane mirrors are placed making an angle θ in between them. Write an expression for the number of images formed if an object is placed in between the mirrors. State the condition, if any.

Ans. n if $n = \frac{360°}{\theta°}$ is odd and object is asymmetrically placed, $n - 1$ if n is even or odd if object is placed symmetrically.

2. Two plane mirrors are placed making an angle θ° in between them. For an object placed in between the mirrors, if angle is gradually increased from 0° to 180°, how will the number of images change: increase, decrease or remain unchanged ? **Ans.** Decrease

3. How many images are formed for a point object kept in between the two plane mirrors at right angles to each other ? Show them by drawing a ray diagram. **Ans.** 3

4. Two plane mirrors are arranged parallel and facing each other at some separation. How many images are formed for a point object kept in between them ? Show the formation of images with the help of a ray diagram. **Ans.** Infinite

5. State *two* uses of a plane mirror.

Multiple choice type :

1. Two plane mirrors are placed making an angle 60° in between them. For an object placed in between the mirrors, the number of images formed will be :
   (a) 3 (b) 6
   (c) 5 (d) infinite. **Ans.** (c) 5

2. In the barber's shop, two plane mirrors are placed :
   (a) perpendicular to earth other
   (b) parallel to each other
   (c) at an angle 60° between them
   (d) at angle 45° between them.
   Ans. (b) parallel to each other

Numericals :

1. State the number of images of an object placed between the two plane mirrors, formed in each case when the mirrors are inclined to each other at (a) 90°, and (b) 60°. **Ans.** (a) 3, (b) 5

2. An object is placed (i) asymmetrically (ii) symmetrically, between two plane mirrors inclined at an angle of 50°. Find the number of images formed. **Ans.** (i) 7, (ii) 6

(C) SPHERICAL MIRRORS, IMAGE FORMATION AND THEIR USES

7.15 SPHERICAL MIRRORS

A spherical mirror is made by silvering a part of a hollow glass sphere. Thus

A reflecting surface which is a part of a sphere is called a spherical mirror.

Types of spherical mirrors : Depending on whether the inner or outer surface of the sphere is silvered, spherical mirrors are of *two* types:

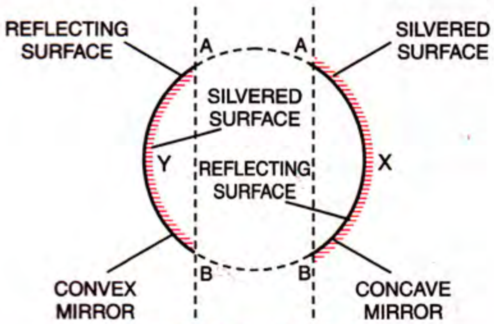


Fig. 7.20 Spherical mirrors

(i) the *concave mirror,* and (ii) the *convex mirror.* In Fig. 7.20, the right part *X* of a hollow sphere is silvered and coated on its outer surface, and it forms the *concave mirror*, while the left part *Y* of the sphere is silvered and coated on its inner surface, and it forms the *convex mirror*.

(i) *Concave mirror*

A concave mirror is made by silvering the outer (or bulging) surface of the piece of a hollow sphere such that the reflection takes place

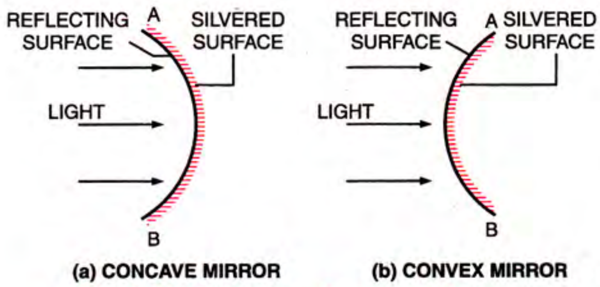


Fig. 7.21 Concave and convex mirrors

from the hollow (or concave) surface as shown in Fig. 7.21 (a).

(ii) *Convex mirror*

A convex mirror is made by silvering the inner surface of the piece of a hollow sphere such that the reflection takes place from the outer (or bulging) surface as shown in Fig. 7.21 (b).

7.16 BRIEF INTRODUCTION OF TERMS RELATED TO A SPHERICAL MIRROR

(1) *Centre of curvature*

The centre of curvature of a mirror is the centre of the sphere of which the mirror is a part.

In Fig. 7.22, it is represented by the symbol *C*.

The normal at any point of the mirror passes through the centre of curvature *C*. In other words, *a line joining any point on the surface of mirror to the centre of curvature C will be normal to the surface of mirror at that point.*

(2) *Radius of curvature*

The radius of sphere of which the spherical mirror is a part, is called the radius of curvature of the mirror.

Thus, it is the distance of centre of curvature *C* from any point on the surface of mirror. In Fig. 7.22, distance *PC* is the radius of curvature. It is represented by the symbol *R*.

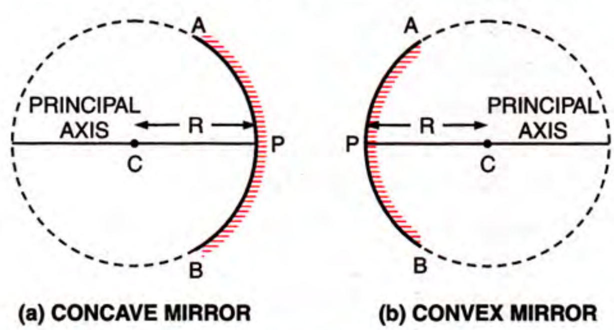


Fig. 7.22 Centre of curvature, radius of curvature, pole, aperture and principal axis

(3) *Pole*

The geometric centre of the spherical surface of mirror is called the pole of mirror.

It is the central point of the surface of the mirror. It is represented by the letter *P* as shown in Fig. 7.22.

(4) *Aperture*

The plane surface area of the mirror through which the light rays enter and fall on the mirror is called its aperture.

Thus for the mirror shown in Fig. 7.22, *AB* is the diameter of aperture.

(5) *Principal axis*

It is the straight line joining the pole of the mirror to its centre of curvature.

In Fig. 7.22, the line *PC* represents the principal axis. It can extend on either side.

7.17 REFLECTION OF LIGHT RAY FROM A SPHERICAL MIRROR

From a spherical mirror, reflection of light follows the same laws of reflection as for the plane surface (*i.e. angle of incidence i = angle of reflection r* and the incident ray, reflected ray and the normal lie in same plane).

Note : In a spherical mirror, to obtain the direction of reflected ray for a given incident ray, first draw a normal at the point of incidence. For this, draw a line joining the point of incidence to the centre of curvature *C**. Then draw a line on the other side of the normal, making an angle (*i.e.,* the angle of reflection) equal to the angle of incidence. This line represents the reflected ray.

Example : In Fig. 7.23, we are to find the direction of reflected ray for an incident ray *AD* on a concave mirror and convex mirror for which *C* is the position of centre of curvature.

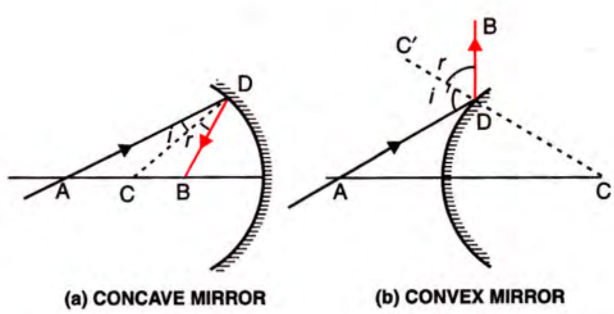


Fig. 7.23 Reflection of a ray of light from a spherical mirror

* The line joining the point of incidence to the centre of curvature is normal to the tangent drawn on the spherical surface at the point of incidence, so it becomes normal at the point of incidence.

For this, the point of incidence D is joined to the centre of curvature C to get the normal DC on the mirror at the point of incidence D. Then the reflected ray DB is drawn such that $\angle BDC = \angle ADC$ in concave mirror and $\angle BDC' = \angle ADC'$ in convex mirror.

7.18 FOCUS AND FOCAL LENGTH

For concave mirror : In Fig. 7.24, the rays of light are incident parallel to its principal axis on a concave mirror. Each ray gets reflected from the mirror obeying the law of reflection (*i.e.*, angle of incidence i = angle of reflection r) for which the dotted line joining the point of incidence to the centre of curvature C acts as normal at the point of incidence. We note that in Fig. 7.24, concave mirror converges the rays on reflection and the rays after reflection pass through a point F on the principal axis. This point is called the *focus* of concave mirror. Thus a concave mirror has a *real focus* because the reflected rays actually meet at this point. The focus is represented by the symbol F. Thus

> *The focus of a concave mirror is a point on the principal axis through which the light rays incident parallel to the principal axis, pass after reflection from the mirror.*

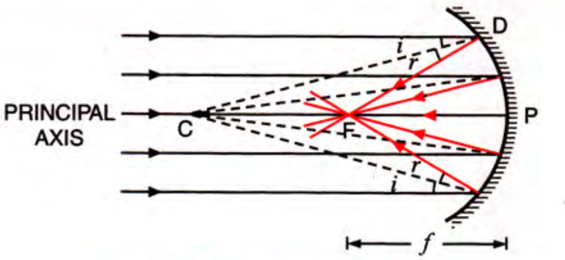


Fig. 7.24 Focus and focal length of a concave mirror

The distance of focus F from the pole P of the mirror is called its focal length. *i.e.*, focal length $f = PF$.

For convex mirror : In Fig. 7.25, the rays of light are incident parallel to the principal axis on a convex mirror. Each ray after reflection appears to diverge and the reflected rays do not meet at any point, but they appear to come from a point F on the principal axis, behind the mirror. This point is called the *focus* of the convex mirror. This point is obtained geometrically, when the reflected rays are produced backwards. Thus a convex mirror has a *virtual focus*. Thus,

> *The focus of a convex mirror is a point on the principal axis from which, the light rays incident parallel to the principal axis, appear to come, after reflection from the mirror.*

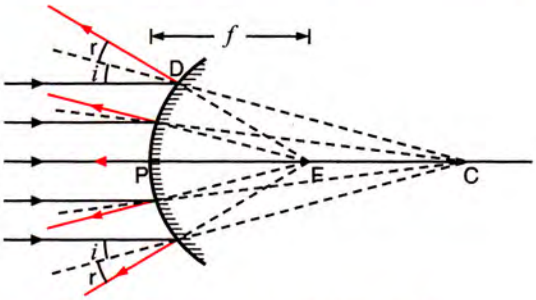
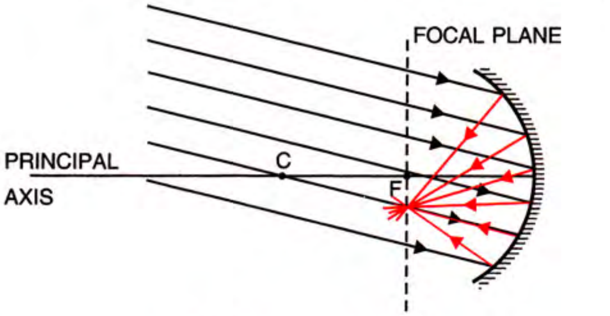


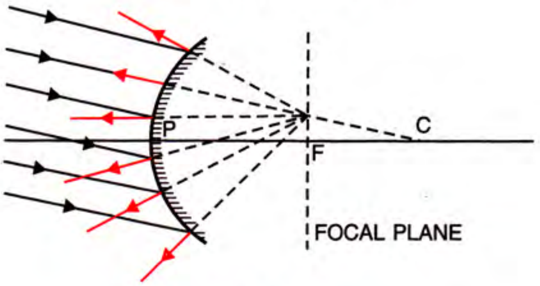
Fig. 7.25 Focus and focal length of a convex mirror

The distance of the focus F from pole P of the mirror is called its focal length *i.e.*, focal length $f = PF$.

Focal plane : A plane passing through the focus and normal to the principal axis of the mirror, is called focal plane. A *parallel beam of light inclined* to the principal axis get focused at a point in this plane [Fig. 7.26(a) and Fig. 7.26(b)]. It is the point where the ray passing through the centre of curvature meets the focal plane.



(a) Concave mirror



(b) Convex mirror

Fig. 7.26 (b) Focal plane

7.19 CONVENIENT RAYS FOR THE CONSTRUCTION OF IMAGE BY RAY DIAGRAM

Although from each point of an object, infinite number of rays travel in all directions, but to find the position and nature of image formed due to reflection from a spherical mirror *by drawing,* we need to consider at least *two* rays incident on the mirror from the same point of the object. Any *two* of the following rays are taken as the convenient incident rays :

(1) A ray passing through the centre of curvature,

(2) A ray parallel to the principal axis,

(3) A ray passing through the focus,

(4) A ray incident at the pole.

(1) *A ray passing through the centre of curvature*

A line joining the centre of curvature to any point on the surface of mirror is normal to the mirror at that point, therefore a ray *AD* passing through the centre of curvature *C* (or appearing to pass through the centre of curvature *C*) is incident normally on the spherical mirror. Since its angle of incidence is zero, therefore the angle of reflection will also be zero and the ray *AD* gets reflected along its own path *DA* as shown in Fig. 7.27. Thus

A ray passing through (or directed towards) the centre of curvature of a spherical mirror, is reflected back along its own path.

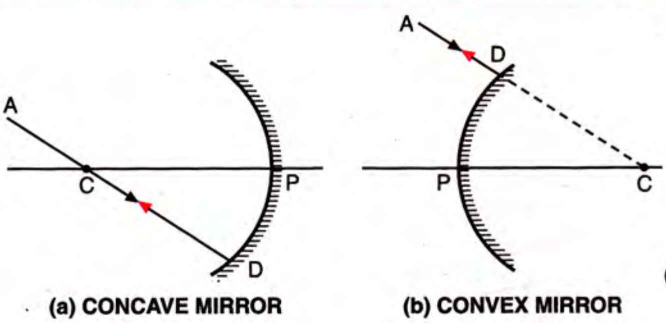


Fig. 7.27 A ray passing through the centre of curvature is reflected back along its own path

(2) *A ray parallel to the principal axis*

A ray of light *AD* incident parallel to the principal axis, after reflection passes either through the focus *F* (*in a concave mirror*) or will appear to come from the focus *F* (*in a convex mirror*) along *DB* as shown in Fig. 7.28 . Thus

A ray incident parallel to the principal axis, after reflection from a spherical mirror either passes or appears to be coming from focus.

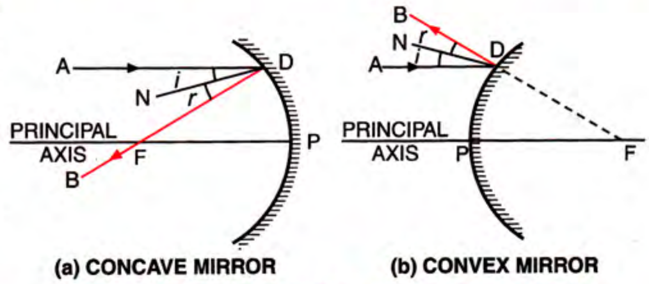


Fig. 7.28 A ray parallel to the principal axis either passes or appears to pass through focus after reflection

(3) *A ray passing through the focus*

A ray of light *AD* incident on the mirror passing through the focus *F* (*in a concave mirror*) or converging at the focus *F* (*in a convex mirror*) after reflection becomes parallel to the principal axis as *DB* (Fig. 7.29). Thus

A ray either incident from the focus (or converging at the focus), after reflection from a spherical mirror becomes parallel to the principal axis.

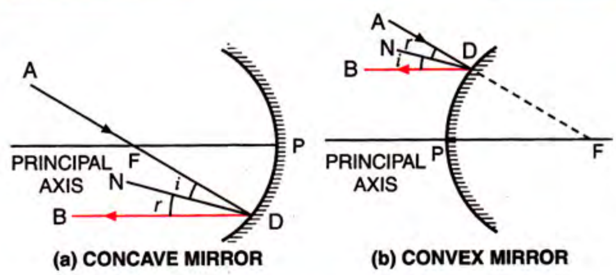


Fig. 7.29 A ray passing through the focus gets reflected parallel to the principal axis

(4) *A ray incident at the pole*

A ray *AP* incident at the pole *P* of the mirror gets reflected along a path *PB* such that the angle of incidence $\angle APC$ is equal to the angle of reflection $\angle BPC$ in a concave mirror (or $\angle APC' = \angle BPC'$ in a convex mirror) as shown in Fig. 7.30. In this case, principal axis itself is the normal at the pole. Thus

For a ray incident at the pole of a spherical mirror, the reflected ray is at an angle of reflection equal to the angle of incidence with principal axis as normal.

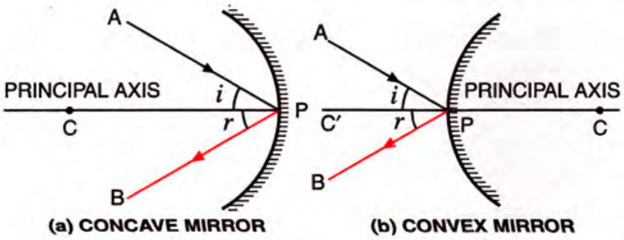


Fig. 7.30 Reflection of a ray incident at the pole

7.20 RAY DIAGRAMS FOR FORMATION OF IMAGES IN A CONCAVE MIRROR

We shall now find the position, size and nature of image by drawing the ray diagram for *a small linear object* placed on the principal axis of a concave mirror at different positions.

Case (i) : *When the object is at infinity*

When the object (e.g. sun) is at infinity, the rays of light reaching the concave mirror even from the different points of the object subtend nearly the same angle at each point of the mirror, so they can be treated to be parallel to each other. In Fig. 7.31, let two rays *AD* and *BE* from the same point of object are incident on the concave mirror, parallel to its principal axis *CP*. They after reflection from the concave mirror pass through its focus *F* as *DF* and *EF* respectively. The two reflected rays *DF* and *EF* meet at the focus *F*. Hence a *real* and *point* image is formed at the focus. Thus

When the object is at infinity, the image is at the focus F. It is (i) Real, (ii) Inverted and (iii) Diminished to a point.

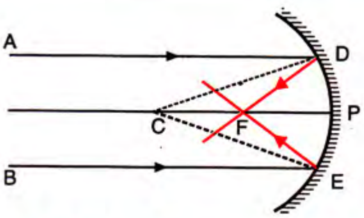


Fig. 7.31 When the object is at infinity

Case (ii) : *When the object is at a far distance*

Consider two rays *AP* and *BD* from the *same point* of an object (*e.g.* a tree) incident on a concave mirror, parallel to each other as shown in Fig 7.32. The incident ray *AP* striking at the pole *P* is reflected along PA_1, such that $\angle APC = \angle A_1PC$ (*i.e.*, $\angle i = \angle r$). Similarly the other ray *BD* is reflected along DA_1 such that $\angle BDC = \angle A_1DC$ (*since DC is normal at the point D*). The reflected rays PA_1 and DA_1 intersect at a point A_1 which is the image of the point of the object. The point A_1 lies on the focal plane of the mirror. Similarly, the rays from other points of the object also converges in the focal plane thus forming the image along A_1F. Hence A_1F is an *inverted, real and highly diminished image formed in the focal plane of the concave mirror.* Thus

When object is at a far distance, image is in the focal plane of the mirror. It is (i) Real, (ii) Inverted, and (iii) Highly diminished.

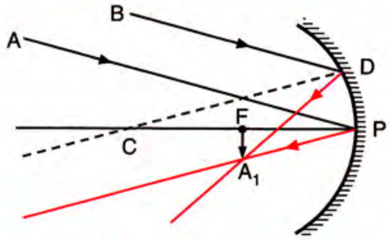


Fig. 7.32 When the object is at far distance

Case (iii) : *When object is beyond the centre of curvature*

In Fig. 7.33, *AB* is an object placed beyond the centre of curvature *C*. Consider two light rays from a point *A* of the object. A ray *AD* incident parallel to the principal axis, after reflection from the concave mirror passes through its focus *F* along DA_1. Another ray *AE* passing through the centre of curvature *C* is incident normally on the mirror, so it gets reflected back as *EA*. The two reflected rays DA_1 and *EA* intersect at a point A_1 to form the image. Similarly, the image is formed at points between A_1 and B_1 for other points of the object between *A* and *B*. So image A_1B_1 is obtained between the focus *F* and the centre of curvature *C*. The image is *real, inverted* and *diminished.* Thus

When object is beyond the centre of curvature C, the image is between the focus F and the centre of curvature C. It is (i) *Real,* (ii) *Inverted, and* (iii) *Diminished.*

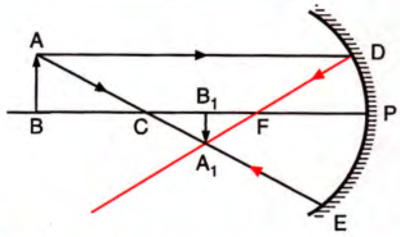


Fig. 7.33 When the object is beyond centre of curvature C

Case (iv) : *When object is at the centre of curvature C*

In Fig. 7.34, AB is an object placed at the centre of curvature C. An incident ray of light AD being parallel to the principal axis, passes through its focus F along DA_1 after reflection. The other ray AE, being incident on the concave mirror through focus F, becomes parallel to the principal axis as EA_1, after reflection. The two reflected rays DA_1 and EA_1 meet at a point A_1 to form the image. Similarly, the image is formed for other points of the object and B_1A_1 is the image of the object AB formed at the centre of curvature C itself. It is *real, inverted and of same size as the object.* Thus

When the object is at the centre of curvature C, the image is also at the centre of curvature C. It is (i) *Real,* (ii) *Inverted, and* (iii) *Size same as that of the object.*

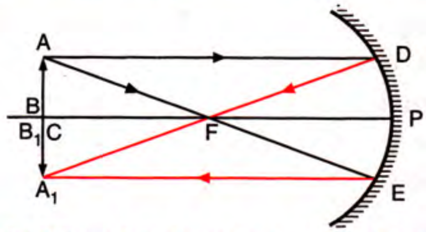


Fig. 7.34 When the object is at centre of curvature C

Case (v) : *When object is between the centre of curvature C and focus F*

In Fig. 7.35, AB is an object placed between C and F. An incident ray of light AD from the point A of the object is parallel to the principal axis, so it passes through its focus F after reflection along DA_1. Another ray AE, being incident on the concave mirror through focus F, becomes parallel to the principal axis as EA_1, after reflection. The two reflected rays DA_1 and EA_1 intersect at a point A_1 to form the image of point A of the object. Similarly, the image is formed on A_1B_1 for the other points on the object AB, thus the image A_1B_1 is formed beyond the centre of curvature C which is *real, inverted* and *magnified.* Thus,

When the object is between the centre of curvature C and the focus F, the image is beyond the centre of curvature C. It is (i) *Real,* (ii) *Inverted, and* (iii) *Magnified.*

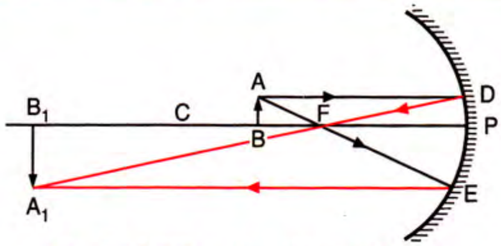


Fig. 7.35 When the object is between centre of curvature C and focus F

Case (vi) : *When object is at the focus F*

In Fig. 7.36, AB is an object placed at the focus F. A ray of light AD is incident on the mirror parallel to the principal axis and so it gets reflected along DF, passing through its focus F. The other ray AE moving in direction CA, appears to be coming from the centre of curvature C, so it gets reflected back along EA. The two reflected rays DF and EA are parallel to each other which are assumed to meet at infinity, so image is *formed at infinity*. In this case image is *real, inverted and highly magnified.* Thus

When the object is at the focus F, the image is at infinity. It is (i) *Real,* (ii) *Inverted, and* (iii) *Highly magnified.*

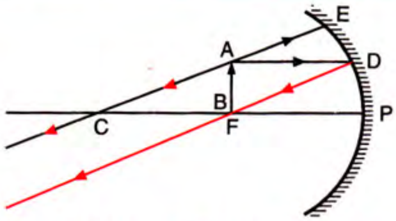


Fig. 7.36 When the object is at focus F

Case (vii) : *When the object is between the focus F and the pole P*

In Fig. 7.37, AB is an object placed between

pole P, and focus F. A light ray AD incident parallel to the principal axis, gets reflected along DF passing through its focus F and the incident ray AE coming from the centre of curvature C gets reflected back along EA. The two reflected rays DF and EA do not intersect each other, but they appear to diverge from a point A_1 (*when produced backwards*). For an eye between C and F, the reflected rays appear to come from A_1 which is the virtual image of A. Similarly, image is formed for other points on the object and an image A_1B_1 is formed behind the mirror which is *virtual, upright* and *magnified.* Thus

When the object is between the focus F and pole P, the image is behind the mirror. It is (i) *Virtual,* (ii) *Upright, and* (iii) *Magnified.*

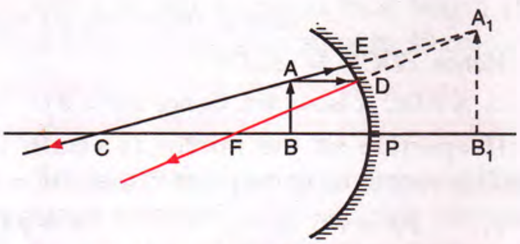


Fig. 7.37 When the object is between focus F and pole P

Note : In this case, as the object AB moves towards its pole P, image A_1B_1 formed behind the mirror, also shifts towards the pole P and its size keeps on decreasing, but it remains bigger than the object AB. Finally when the object AB comes very close to the pole P of the mirror, the virtual image will be at the pole and it is of size same as of object.

Inference : *In case of a concave mirror, the image formed can be real as well as virtual; it can be diminished, of the same size as well as magnified. The nature and size of the image depends on the position of object. For the object situated beyond focus, the image is always real and inverted, whereas for the object situated between the focus and pole, the image is upright and virtual.* The image is diminished when the object is beyond centre of curvature, but it becomes magnified as the object comes within the centre of curvature. The image is of size of the object when the object is at the centre of curvature.

The table below gives the position, size and nature of the image formed by a concave mirror corresponding to the different positions of the object.

Position, size and nature of the image formed by a concave mirror for different positions of the object.

No.	Position of the object	Position of the image	Size of the image	Nature of the image
1	At *infinity*	At the *focus*	*Diminished* to a point	*Real & inverted*
2	At very far distance	In focal plane	Highly *diminished*	*Real & inverted*
3	Beyond the *centre of curvature*	Between the *centre of curvature and focus*	*Diminished*	*Real & inverted*
4	At *the centre of curvature*	*At centre of curvature*	*Same size*	*Real & inverted*
5	Between the *centre of curvature and focus*	Beyond the *centre of curvature*	*Magnified*	*Real & inverted*
6	At *focus*	At *infinity*	*Highly magnified*	*Real & inverted*
7.	Between the *focus and pole*	Behind the mirror	*Magnified*	*Virtual and upright*

7.21 RAY DIAGRAM FOR FORMATION OF IMAGE IN A CONVEX MIRROR

In Fig. 7.38, AB is a linear object placed in front of a convex mirror. Consider two rays starting from a point A of the object. A ray of light AD, incident parallel to the principal axis is reflected along DM such that it appears to diverge from its focus F. The other ray AE travelling towards the centre of curvature C, falls normally on the mirror, so it is reflected back as EA along the same path. The *two* reflected rays DM and EA meet at a point A_1 when they are produced backwards. In other words, the reflected rays appear to come from a point A_1

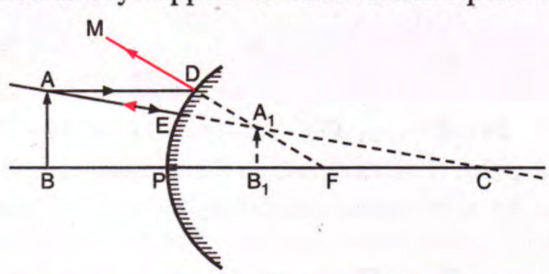


Fig. 7.38 Image formation in convex mirror

which is the virtual image of A. Similarly, for the rays incident from the other points of the object, a virtual image is formed along A_1B_1 which is *situated between the pole and focus*. The image is *virtual, upright and diminished.* Thus

> *When the object is in front of a convex mirror, the image is between the pole P and focus F on the other side of the mirror. It is* (i) *Virtual,* (ii) *Upright, and* (iii) *Diminished.*

Note : When the object, in front of a convex mirror, is at a distance equal to the focal length of mirror, the image is exactly at the midpoint between its pole and focus.

Inference : *In a convex mirror, the image formed is always virtual, upright, and diminished, It is always situated between its pole and focus, irrespective of the distance of object in front of the mirror.* As the object comes closer to the mirror from a far distance, its image shifts from focus towards the pole and increases in size.

The table below gives the position, size and nature of image formed by a convex mirror for the different positions of the object.

Position, size and nature of image formed by a convex mirror

No.	Position of the object	Position of the image	Size of the image	Nature of the image
1	At *infinity*	At *focus*	*Diminished* to a point	*Virtual* and *upright*
2.	At any other point	Between *focus and pole*	*Diminished*	*Virtual* and *upright*

7.22 RELATIONSHIP BETWEEN THE FOCAL LENGTH AND RADIUS OF CURVATURE

> *The focal length of a spherical mirror is equal to half of its radius of curvature. i.e.*
>
> $$f = \frac{1}{2}R \quad ....(7.5)$$

Proof* : In Fig. 7.39 and Fig. 7.40, P is the pole, C is the centre of curvature and F is the focus of the mirror. The distance PF is equal to the focal length f the distance PC is equal to the radius of curvature R of the mirror.

For concave mirror –

In Fig. 7.39, a ray light BD, parallel to the principal axis PC, is incident on the concave mirror PD. After reflection, it goes along DR passing through its focus F.

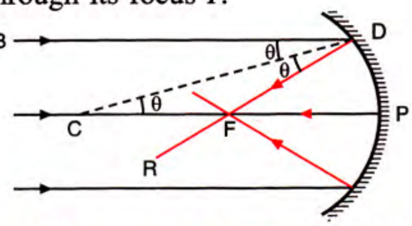


Fig. 7.39 Relationship between f and R for a concave mirror

Then $\angle BDC = \angle DCF$ (alternate angles)

and $\angle BDC = \angle CDF$ (law of reflection, $\angle i = \angle r$)

Hence $\angle DCF = \angle CDF$

$\therefore$ Δ FDC is isosceles. Hence $DF = FC$

If aperture of the mirror is small, the point D is very close to the point P, then $DF = PF$

$\therefore \quad PF = FC$ or $PF + PF = PF + FC$

or $\quad 2PF = PC$

or $\quad PF = \frac{1}{2} PC$ or $f = \frac{1}{2} R$

For convex mirror –

In Fig. 7.40, a ray of light BD incident on the convex mirror, parallel to the principal axis PC, after reflection appears to come from its focus F. At the point of incidence D, the normal on mirror is DC.

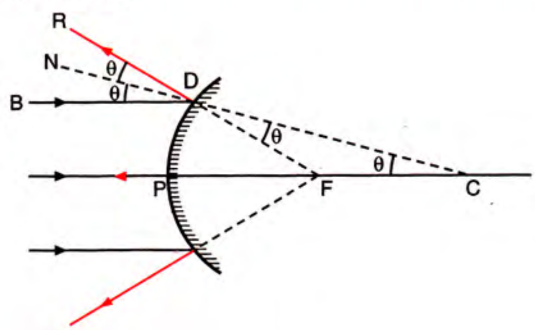


Fig. 7.40 Relationship between f and R for a convex mirror

Then $\angle BDN = \angle FCD$ (corresponding angles)

$\angle BDN = \angle NDR$ (law of reflection, $\angle i = \angle r$)

and $\angle NDR = \angle CDF$ (vertically opposite angles)

* Not included in the syllabus

Hence $\angle FCD = \angle CDF$

$\therefore$ Δ FDC is isosceles. Hence, $DF = FC$

If the aperture of the mirror is small, the point D is very close to the point P. Then $DF = PF$.

$$\therefore \quad PF = FC \text{ or } PF + PF = PF + FC$$

$$\text{or} \quad 2PF = PC$$

$$\text{or} \quad PF = \frac{1}{2} PC \text{ or } f = \frac{1}{2} R$$

Thus, *for a spherical mirror (both concave and convex), focal length is half of its radius of curvature.*

Examples : **(1)** A concave mirror of radius of curvature 20 cm has its focal length equal to 10 cm.

(2) A convex mirror of focal length 15 cm has its radius of curvature equal to 30 cm.

7.23 SIGN CONVENTION FOR THE MEASUREMENT OF DISTANCES

To specify the position of object and image, we need a reference point and sign convention. We follow the *cartesian* sign convention, according to which the rules are :

(i) *All distances are measured from the pole of the mirror taken as origin.* The rays are made incident from the left.

(ii) *The distances measured along the principal axis in the direction of incident light, are positive while those opposite to the incident light, are negative.*

(iii) *The distances above the principal axis are taken positive and those below the principal axis are taken negative.*

This convention gives the focal length of a *concave mirror* to be *negative* (since in Fig. 7.24. *PF* is the distance measure opposite to the incident rays), and that of *convex mirror* to be *positive* (since in Fig. 7.25, *PF* is the distance measured in the direction of incident rays). For convenience, the object is placed to the left of the mirror so that the graphical convention of sign comes into operation.

Fig. 7.41 shows the sign convention in concave and convex mirror.

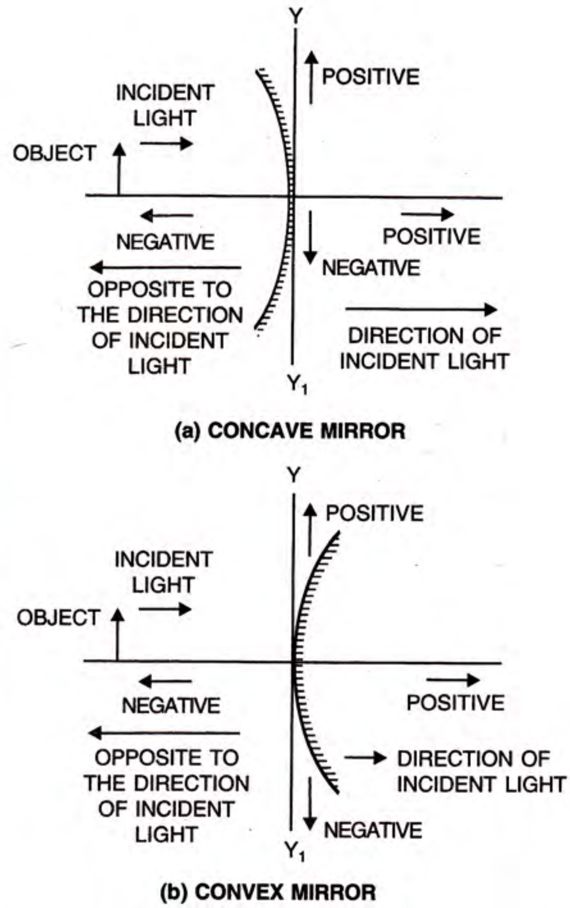


Fig. 7.41 Sign convention

7.24 FORMULAE FOR THE SPHERICAL MIRROR

(1) The expression relating the distance of object u, distance of image v and focal length f for a spherical mirror, is called the formula for spherical mirror. It is gives as :

$$\boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}} \qquad \text{....(7.6)}$$

In the above relation, the values of known quantities out of u, v and f are substituted with their proper sign. For a concave mirror, the values of u and f are always negative, while the value of v is negative for a real image and positive for a virtual image. For a convex mirror, the value of u is always negative and the values of v and f are always positive.

(2) If the length of the object and image are measured perpendicular to the principal axis, *the ratio of length of the image to the length of the object, is called linear magnification.* If length of the image is I and that of the oject is O, then

$$\text{Magnification } m = \frac{\text{Length of the image } (I)}{\text{Length of the object } (O)} = \frac{\text{Distance of image } (v)}{\text{Distance of object } (u)}$$

or $$\boxed{m = \frac{I}{O} = -\frac{v}{u}} \quad ....(7.7)$$

For the real image, u and v both are negative, so linear magnification m is negative. For virtual image, u is negative and v is positive, so linear magnification m is positive. A real image is always inverted, while a virtual image is always erect.

7.25 USES OF SPHERICAL MIRRORS

Uses of a concave mirror

(1) As a shaving mirror : When a concave mirror is held near the face (such that face is between the pole and focus of mirror), it gives an upright and magnified image as shown in Fig. 7.37 and hence even the tiny hairs on the face can easily be seen. For this, a concave mirror of *large focal length* (so that the face always lies between its focus and the pole) and *large aperture* (so as to view the entire face) is used.

(2) As a reflector : *In torch, search light, and head light of automobiles, cars or cycles* etc., a concave polished metallic surface is used as a reflector to obtain a parallel beam of light. For this, the source of light (*i.e.*, bulb) is placed at the focus of concave reflector. The rays of light from the bulb fall on the concave reflector which after reflection form a parallel beam (Fig. 7.42).

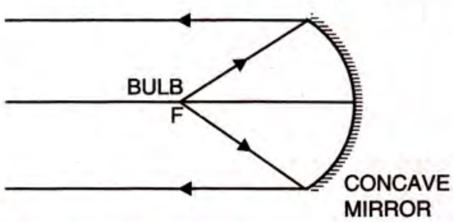


Fig. 7.42 Use of a concave mirror as a reflector

(3) As a dentist's head mirror : If a parallel beam of light is incident on a concave mirror, it focuses the beam to a point [Fig. 7.26(a)]. This fact enables us to use it as a doctor's head mirror to concentrate a light beam on a small area of the body part (such as teeth, nose, throat, ear, etc.) to be examined. For this, a parallel beam of light is made to fall on a concave mirror attached to the band tied at the fore-head of doctor examining the body part.

Uses of a convex mirror

(1) As a reflector in street lamps : A convex polished metallic surface is used in street lamp as a reflector so as to diverge light over a larger area.

(2) As a rear view mirror : A convex mirror diverges the incident light beam and always forms a virtual, small and erect image between its pole and focus. This fact enables the driver to use it as a rear view mirror in vehicles to see all the traffic approaching from behind. Although a plane mirror can also be used for the purpose, but a convex mirror provides a much *wider field of view* as compared to a plane mirror of the *same size*. The ray diagrams in Fig. 7.43 show how a convex mirror provides a wider field of view than a plane mirror of the same aperture. Here D is the position of the driver of the vehicle.

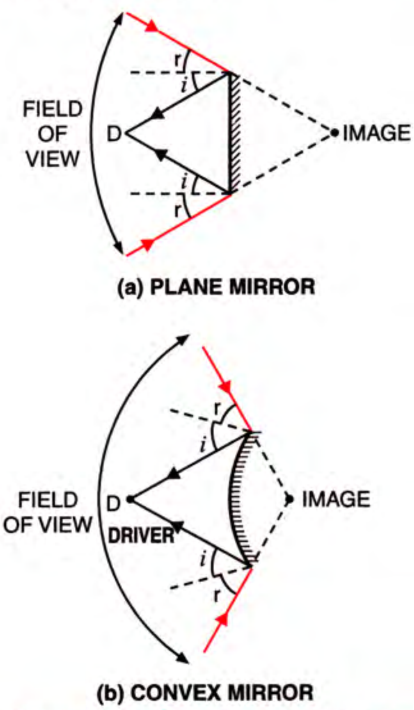


Fig. 7.43 Use of a convex mirror as a rear view mirror

7.26 DISTINCTION BETWEEN A PLANE MIRROR, CONCAVE MIRROR AND CONVEX MIRROR (WITHOUT TOUCHING)

To distinguish between a plane mirror, concave mirror and convex mirror, the given mirror is held near the face and image is seen.

There can be the following *three* cases :

Case (i) : If image is *upright, of same size* and it does not change in size by moving the mirror towards or away from the face, the mirror is *plane.*

Case (ii) : If image is *upright, magnified,* and increases in size on small movement of the mirror away, the mirror is *concave.*

Case (iii) : If image is *upright, diminished* and decreases in size on small movement of the mirror away, the mirror is *convex.*

7.27 DIFFERENCE BETWEEN A CONCAVE AND CONVEX MIRROR

Difference between a concave and convex mirror

Concave mirror	*Convex mirror*
1. It is made by silvering the outer surface of a part of the hollow sphere, so reflection takes place from the inner surface.	1. It is made by silvering the inner surface of a part of the hollow sphere, so reflection takes place from the bulging surface.
2. The light rays incident on it converge after reflection.	2. The light rays incident on it diverge after reflection.
3. The image formed by it is real as well as virtual. For all positions of the object at or beyond the focus, the image is real, while for positions of the object between the focus and pole, the image is virtual.	3. The image formed by it is always virtual for all positions of the object in front of it.
4. For object away from the centre of curvature, the image is diminished, for object at centre of curvature, image is of same size and for object within the centre of curvature, image is magnified.	4. The image is always diminished for all positions of the object in front of it.

EXAMPLES

1. Complete the ray diagram shown in Fig. 7.44 to show the formation of image for parallel rays incident on a concave mirror. State position, nature and size of the image formed.

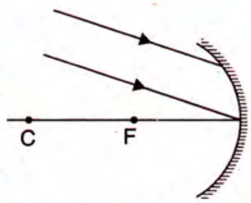


Fig. 7.44

The completed ray diagram is shown in Fig. 7.45. The image is formed at the focus *F*. It is **real, inverted** and **diminished**.

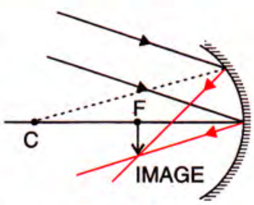


Fig. 7.45

2. Complete the ray diagram shown in Fig. 7.46 to show the formation of image for parallel rays incident on a convex mirror. State position, nature and size of the image formed.

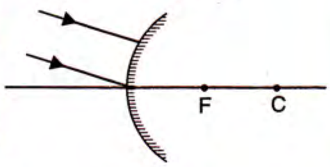


Fig. 7.46

The completed ray diagram is shown in Fig. 7.47. The image is formed at the focus *F* (behind the mirror). It is **virtual, erect** and **diminished**.

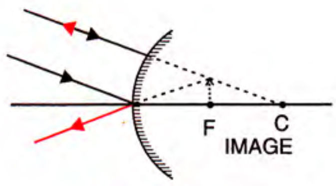


Fig. 7.47

3. In case of a convex mirror, if object is moved away from the mirror, how do the position, size and nature of image change ?

As the object is moved away from a convex mirror, the distance of virtual image from the mirror (formed behind it between pole and focus) increases *i.e.*, the image shifts from the pole towards the focus and the size of the image gradually decreases. When the object is at infinity (very far), the image is at its focus. The image is always erect and virtual.

4. An object is brought from a far distance towards a concave mirror. How do the nature, position and size of image change ?

When object is very far from the concave mirror, its image is at the focus and it is real, diminished, and inverted. As the object is brought towards the mirror, the image shifts away from the mirror and its size increases, but it remains smaller than the object. When the object is at centre of curvature of the mirror, the image is also at the centre of curvature and it is of size equal to the size of the object. By further bringing the object towards the mirror, the image gets magnified and it moves away from the centre of curvature. When object is at focus of mirror, the image is at infinity. The image remains real and inverted. If the object is further moved towards the mirror, the image now becomes virtual, erect and magnified and it is formed behind the mirror.

5. You are given a concave mirror of focal length 10 cm, a point source of light and a screen placed at distance 30 cm in front of mirror. How can you obtain a bright patch of light on screen, of size equal to that of the aperture of mirror ? Draw diagram to explain your answer.

By placing the point source of light at the focus of the concave mirror, it is possible to obtain a bright patch on the screen, of size equal to that of the aperture of the mirror. The completed ray diagram is shown in Fig. 7.48.

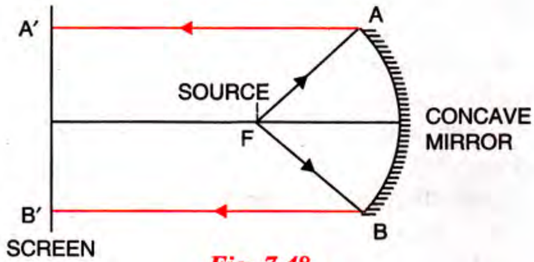


Fig. 7.48

6. What is the focal length of a concave mirror of radius of curvature 16·0 cm ?

Given, radius of curvature = 16·0 cm

$$\text{Focal length} = \frac{1}{2} \times \text{Radius of curvature}$$
$$= \frac{1}{2} \times 16{\cdot}0 \text{ cm} = \mathbf{8{\cdot}0 \text{ cm}}$$

7. A concave mirror is a part of hollow sphere of radius 40 cm. What will be the focal length of concave mirror ?

Given : radius of curvature R = 40 cm

$$\therefore \quad \text{Focal length } f = \frac{\text{Radius of curvature } R}{2}$$
$$= \frac{40}{2} = \mathbf{20 \text{ cm}}$$

8. The focal length of a convex mirror is 10 cm. Find the radius of curvature of mirror.

Given : Focal length f = 10 cm

$\therefore$ Radius of curvature $R = 2 \times$ focal length f

$$= 2 \times 10 = \mathbf{20 \text{ cm}}$$

9. For an object placed at a distance 20 cm from a concave mirror, the image is formed at the same position. What is the focal length of the mirror ?

For an object placed at the centre of curvature of a concave mirror, the image is formed at the centre of curvature itself. Thus radius of curvature R = 20 cm

$$\text{Focal length } f = \frac{\text{Radius of curvature } R}{2}$$
$$= \frac{20 \text{ cm}}{2} = \mathbf{10 \text{ cm}}$$

10. The image of an object placed at a distance of 30 cm on the principal axis of a concave mirror from its pole, is formed on the object itself. Find (a) the focal length and (b) linear magnification of mirror.

Since the image of an object placed at the centre of curvature of a concave mirror is formed at the centre of curvature, hence according to the question, radius of curvature of mirror R = 30 cm.

(a) $$\text{Focal length } f = \frac{1}{2} \times \text{Radius of curvature}$$
$$= \frac{1}{2} \times 30 \text{ cm} = \mathbf{15 \text{ cm}}$$

(b) Now u = 30 cm (negative),
v = 30 cm (negative)

$\therefore$ Linear magnification

$$m = -\frac{v}{u} = -\left(\frac{-30}{-30}\right) = \mathbf{-1}$$

11. An object is placed at a distance of 48 cm in front of a concave mirror of focal length 24 cm.

(a) Find the position of image.

(b) What will be the nature of image ?

Given : f = 24 cm (negative),
u = 48 cm (negative)

(a) From relation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{(-24)} - \frac{1}{(-48)}$$

or $$\frac{1}{v} = \frac{-2+1}{48} = \frac{-1}{48} \quad \text{or} \quad v = \mathbf{-48 \text{ cm}}$$

Alternative : The object is at the centre of curvature of concave mirror, so image will form on itself *i.e.*, at distance 48 cm in front of mirror.

(b) The image is at a distance **48 cm in front** of mirror. The image is **inverted**, **real** and **of same size** as object.

12. An object is placed at a distance of 15 cm in front of a convex mirror of radius of curvature 10 cm. (a) Where will the image form ? (b) Find the magnification *m*. (c) What will be the nature of image real or virtual ?

Given : $R = 10$ cm, $f = \frac{R}{2} = 5$ cm (positive),

$u = 15$ cm (negative), $v = ?$

(a) From relation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{v} + \frac{1}{(-15)} = \frac{1}{5}$$

or $$\frac{1}{v} = \frac{1}{5} + \frac{1}{15} = \frac{4}{15}$$

or $$v = \frac{15}{4} = \mathbf{3{\cdot}75\ cm}$$

Thus the image will form at a distance **3·75 cm behind** the mirror.

(b) Magnification $m = -\frac{v}{u} = -\frac{3{\cdot}75}{(-15)} = \frac{1}{4}$

Thus the size of image is **one-fourth** the size of the object.

(c) The image will be **virtual** and **erect**.

13. When an object is placed at a distance of 40 cm from a concave mirror, the size of image is one fourth that of the object. (a) Calculate the distance of image from the mirror. (b) What will be the focal length of the mirror ?

Given : $u = 40$ cm (negative),

$m = \frac{1}{4}$ (negative for the real image)

(a) From $m = -\frac{v}{u}$, $-\frac{1}{4} = -\frac{v}{(-40)}$ or $v = \mathbf{-10\ cm}$

Thus the image is formed at a distance **10 cm in front** of the mirror.

(b) Now from relation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{f} = \frac{1}{(-40)} + \frac{1}{(-10)}$$

$$= \frac{-5}{40}$$

or $$f = \frac{-40}{5} = \mathbf{-8\ cm}$$

i.e., the focal length of concave mirror is **8 cm**.

14. At what distance in front of a concave mirror of focal length 10 cm, an object be placed so that its real image of size five times that of the object is obtained ?

Given : $f = 10$ cm (negative),

$m = 5$ (negative for the real image)

But $m = -\frac{v}{u}$ ∴ $-5 = -\frac{v}{u}$ or $v = 5u$

Now from relation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{u} + \frac{1}{5u} = \frac{1}{-10}$$

or $$\frac{6}{5u} = \frac{-1}{10}$$

or $$u = \mathbf{-12\ cm}$$

Thus the object should be placed at a distance **12 cm in front** of the mirror.

15. At what distance in front of a concave mirror of focal length 10 cm, an object be placed so that its virtual image of size five times that of the object is obtained?

Given : $f = 10$ cm (negative),

$m = 5$ (positive for the virtual image)

But $m = -\frac{v}{u}$ ∴ $5 = -\frac{v}{u}$ or $v = -5u$

Now from relation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{u} + \frac{1}{(-5u)} = \frac{1}{-10}$$

or $$\frac{4}{5u} = \frac{-1}{10}$$

or $$u = \mathbf{-8\ cm}$$

Thus the object should be placed at a distance **8 cm in front** of the mirror.

16. A convex mirror forms the image of an object placed at a distance 40 cm in front of mirror, at distance 10 cm. Find the focal length of mirror.

Given : $u = 40$ cm (negative),

$v = 10$ (positive), $f = ?$

since the image formed by a convex mirror is always virtual, erect and on other side of mirror.

From relation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{(-40)} + \frac{1}{10} = \frac{1}{f}$$

or $$\frac{1}{f} = \frac{-1+4}{40}$$

or $$\frac{1}{f} = \frac{3}{40}$$

or $$f = \frac{40}{3} = \mathbf{13{\cdot}33\ cm}$$

17. The focal length of a convex mirror is 40 cm. A point source of light is kept at distance 40 cm from the mirror. Find the distance of image from the mirror.

Given : $f = 40$ cm (positive),
$u = 40$ (negative)

From relation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{(-40)} + \frac{1}{v} = \frac{1}{40}$$

or $$\frac{1}{v} = \frac{1}{40} + \frac{1}{40} = \frac{1}{20}$$

or v = **20 cm**

i.e., the image is formed at distance **20 cm behind** the mirror.

18. A convex mirror forms an erect image of an object of size one-third the size of object. If radius of curvature of convex mirror is 36 cm, find the position of object.

Given : $m = \frac{1}{3}$ (positive) for the erect (or virtual) image, $R = 36$ cm (positive).

$\therefore$ From relation $f = \frac{R}{2} = 18$ cm (positive).

From relation $m = -\frac{v}{u}$,

$$\frac{1}{3} = -\frac{v}{u} \quad \therefore v = -\frac{1}{3}u$$

From mirror's formula $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{u} + \frac{1}{(-u/3)} = \frac{1}{18}$$

or $$\frac{-2}{u} = \frac{1}{18} \quad \text{or} \quad u = -\mathbf{36\ cm}$$

Thus the object is at a distance **36 cm in front** of the mirror.

EXERCISE 7(C)

1. What is a spherical mirror ?
2. Name the *two* kinds of spherical mirrors and distinguish between them.
3. Define the terms pole, principal axis and centre of curvature with reference to a spherical mirror.
4. Draw suitable diagrams to illustrate the action of (i) concave mirror, and (ii) convex mirror, on a beam of light incident parallel to the principal axis.
5. Name the spherical mirror which (i) diverges (ii) converges the beam of light incident on it. Justify your answer by drawing a ray diagram in each case.
6. Define the terms focus and focal length of a concave mirror. Draw diagram to illustrate your answer.
7. Explain the meaning of the terms focus and focal length in case of a convex mirror, with the help of a suitable ray diagram.
8. State the direction of incident ray which after reflection from a spherical mirror retraces its path. Give a reason to your answer.

   Ans. Incident ray is directed towards the centre of curvature

   Reason : The ray is normal to the spherical mirror, so $\angle i = 0$, $\therefore \angle r = 0$.
9. (i) Name the mirrors shown in Fig. 7.49 (a) and (b).

   (ii) In each case (a) and (b), draw the reflected rays for the given incident rays and mark focus by the symbol *F*.

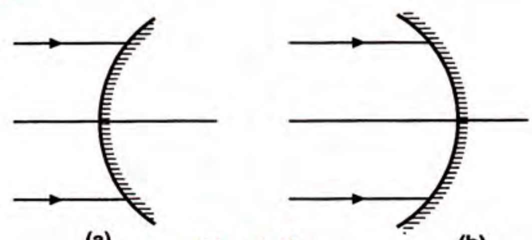


Fig. 7.49

Ans. (i) (a) convex mirror (b) concave mirror

10. Complete the following diagrams in Fig. 7.50 by drawing the reflected rays for the incident rays 1 and 2.

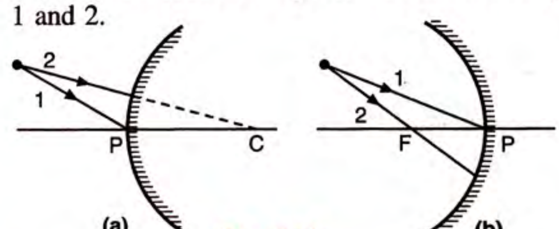


Fig. 7.50

11. Complete the following diagrams shown in Fig. 7.51 by drawing the reflected ray for each of the incident ray *A* and *B*.

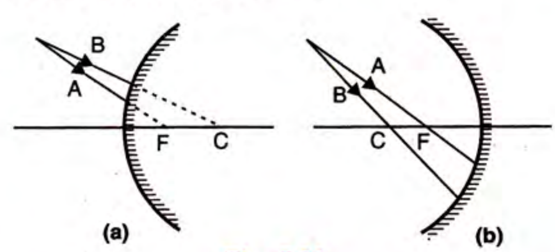


Fig. 7.51

12. State the *two* convenient rays that are chosen to construct the image by a spherical mirror for a given object ? Explain your answer with the help of suitable ray diagrams.

13. Fig. 7.52 shows a concave mirror with its pole at *P*, focus *F* and centre of curvature *C*. Draw ray diagram to show the formation of image of an object *OA*.

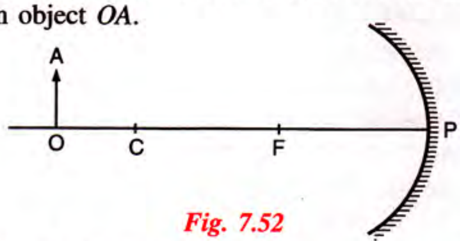


Fig. 7.52

14. Fig. 7.53 shows a concave mirror with its pole at *P*, focus *F* and centre of curvature *C*. Draw ray diagram to show the formation of image of an object *OA*.

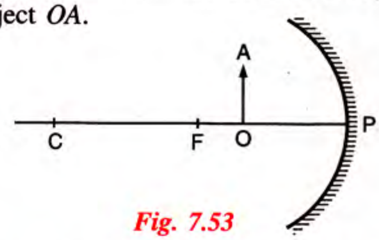


Fig. 7.53

15. The diagram below in Fig. 7.54 shows a convex mirror. *C* is its centre of curvature and *F* is its focus. (i) Draw *two* rays from *A* and hence locate the position of image of object *OA*. Label the image *IB*. (ii) State *three* characteristics of the image.

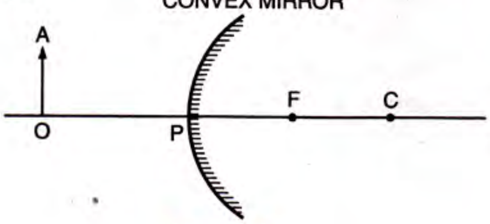


Fig. 7.54

Ans. (ii) Erect, virtual and diminished

16. Draw a ray diagram to show the formation of image by a concave mirror for an object placed between its pole and focus. State *three* characteristics of the image.

17. Draw a ray diagram to show the formation of image by a concave mirror for the object beyond its centre of curvature. State *three* characteristics of the image.

18. Draw a ray diagram to show the formation of image of an object kept in front of a convex mirror. State *three* characteristics of the image.

19. Name the mirror which always produces an erect and virtual image. How is the size of image related to the size of object ?

Ans. Convex mirror, image is shorter than the object

20. (a) For what position of object, the image formed by a concave mirror is magnified and erect ?
    (b) State whether the image in part (a) is real or virtual ?

    Ans. (a) Between pole and focus, (b) virtual

21. (a) State the position of object for which the image formed by a concave mirror is of same size.
    (b) Write *two* more characteristics of the image.

Ans. (a) At centre of curvature. (b) Real and inverted

22. (a) What is a real image ?
    (b) What type of mirror can be used to obtain a real image of an object ?
    (c) Does the mirror mentioned in part (b) form real image for all locations of the object ?

    Ans. (a) A real image is one which can be obtained on a screen, (b) Concave, (c) No

23. Discuss the position and nature of image formed by a concave mirror when an object is moved from infinity towards the pole of mirror.

24. Discuss the position and nature of image formed by a convex mirror when an object is moved from infinity towards the pole of mirror.

25. Name the kind of mirror used to obtain :
    (a) a real and enlarged image,
    (b) a virtual and enlarged image,
    (c) a virtual and diminished image,
    (d) a real and diminished image.

    Ans.(a) concave, (b) concave, (c) convex, (d) concave

26. How is the focal length of a spherical mirror related to its radius of curvature ? **Ans.** $f = \frac{1}{2}R$

27. Write the spherical mirror's formula and explain the meaning of each symbol used in it.

    Ans. $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

28. What is meant by magnification ? Write its expression. What is its sign for the (a) real (b) virtual, image ?

29. At what maximum distance the image in a convex mirror can be obtained ? What will be the location of object then ? **Ans.** focal length, infinity

30. At what maximum distance from a concave mirror, the image can be obtained ? What will be the location of object for it ? **Ans.** infinity, focus.

31. How will you distinguish between a plane mirror, a concave mirror and a convex mirror, without touching them ?
32. State *two* uses of a concave mirror.
33. State the kind of mirror used
(a) by a dentist, (b) as a search-light reflector.
Ans. (a) concave, (b) concave
34. (a) When a concave mirror is used as a shaving mirror, where is the person's face in relation to the focus of mirror ?
(b) State *three* characteristics of the image seen in part (a).
Ans. (a) Between pole and focus.
(b) Erect, virtual and magnified
35. Which mirror will you prefer to use as a rear view mirror in a car : plane mirror or convex mirror ? Give *one* reason.
36. Why does a driver use a convex mirror instead of a plane mirror as a rear view mirror ? Illustrate your answer with the help of a ray diagram.

Multiple choice type :

1. For an incident ray directed towards centre of curvature of a spherical mirror, the reflected ray :
(a) retraces its path
(b) passes through the focus
(c) passes through the pole
(d) becomes parallel to the principal axis.
Ans. (a) retraces its path
2. The image formed by a convex mirror is :
(a) erect and diminished
(b) erect and enlarged
(c) inverted and diminished
(d) inverted and enlarged.
Ans. (a) erect and diminished
3. A real and enlarged image can be obtained by using a :
(a) convex mirror (b) plane mirror
(c) concave mirror
(d) either convex or plane mirror.
Ans. (c) concave mirror

Numericals :

1. The radius of curvature of a convex mirror is 40 cm. Find its focal length. **Ans.** 20 cm.
2. The focal length of a concave mirror is 10 cm. Find its radius of curvature. **Ans.** 20 cm.
3. An object of height 2 cm is placed at a distance 20 cm in front of a concave mirror of focal length 12 cm. Find the position, size and nature of the image.
Ans. 30 cm in front of mirror, 3 cm high, real, inverted and magnified
4. An object is placed at 4 cm distance in front of a concave mirror of radius of curvature 24 cm. Find the position of image. Is the image magnified ? **Ans.** 6 cm behind the mirror, Yes
5. At what distance from a concave mirror of focal length 25 cm should an object be placed so that the size of image is equal to the size of the object. **Ans.** 50 cm
6. An object 5 cm high is placed at a distance 60 cm in front of a concave mirror of focal length 10 cm. Find (i) the position and (ii) size, of the image.
Ans. (i) 12 cm in front of the mirror, (ii) 1 cm
7. A point light source is kept in front of a convex mirror at a distance of 40 cm. The focal length of the mirror is 40 cm. Find the position of image.
Ans. Behind the mirror at a distance 20 cm
8. When an object of height 1 cm is kept at a distance 4 cm from a concave mirror, its erect image of height 1·5 cm is formed at a distance 6 cm behind the mirror. Find the focal length of mirror.
Ans. 12 cm
9. An object of length 4 cm is placed in front of a concave mirror at distance 30 cm. The focal length of mirror is 15 cm. (a) Where will the image form ? (b) What will be the length of image ?
Ans. (a) 30 cm in front of mirror, (b) 4 cm.
10. A concave mirror forms a real image of an object placed in front of it at a distance 30 cm, of size three times the size of object. Find (a) the focal length of mirror (b) position of image.
Ans. (a) 22·5 cm, (b) 90 cm in front of mirror.
11. A concave mirror forms a virtual image of size twice that of the object placed at a distance 5 cm from it. Find : (a) the focal length of the mirrror (b) position of image.
Ans. (a) 10 cm, (b) 10 cm behind the mirror.
12. The image formed by a convex mirror is of size one-third the size of object. How are u and v related ? **Ans.** $v = -\frac{1}{3}u$ or $u = -3v$
13. The erect image formed by a concave mirror is of size double the size of object. How are u and v related ? **Ans.** $v = 2u$
14. The magnification for a mirror is –3. How are u and v related ? **Ans.** $v = -3u$

8 PROPAGATION OF SOUND WAVES

Syllabus :

(i) *Nature of sound waves, Requirement of a medium for sound waves to travel; propagation and speed in different media; comparison with speed of light.*

Scope – Sound propagation, terms — frequency (f), wavelength (λ), velocity (V), relation $V = f\lambda$ (simple numerical problems), effect of different factors on the speed of sound; comparison of speed of sound with speed of light, consequences of the large difference in these speeds in air, thunder and lightning.

(ii) *Infrasonic, sonic, ultrasonic frequencies and their applications.*

Scope – Elementary ideas and simple applications only. Difference between ultrasonic and supersonic.

(A) PRODUCTION AND PROPAGATION OF SOUND WAVE

8.1 SOUND AND ITS PRODUCTION FROM VIBRATIONS

Everyday we hear sounds from various sources. For example, we hear sound of morning alarm, church bell, school bell, horn of a car (or bus), barking of dog, music from different instruments, *etc*. Although we do not see sound coming to us, but sound reaches our ears in the form of waves formed due to the vibrations of particles of the medium. The waves carry the mechanical energy of the vibrating particles with them so as to produce a sensation of hearing in our ears. Thus

Sound is a form of energy that produces the sensation of hearing in our ears.

Sound is produced by vibrations

Sound is produced when a body vibrates. Following experiments demonstrate this fact.

Experiment (1) : Stretch a string by holding one end in mouth between the teeth and the other end in one hand as shown in Fig. 8.1. Pluck it by the other hand near the middle.

It is noticed that the string starts vibrating and simultaneously a sound is heard. After some time when the string stops vibrating, no sound is heard.

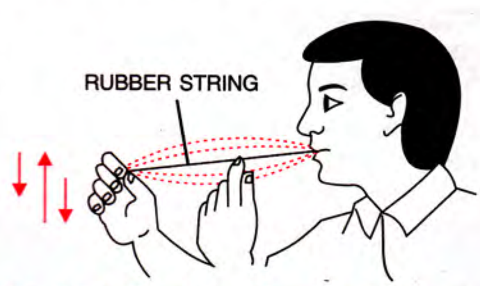


Fig. 8.1 A vibrating rubber string produces sound

Experiment (2) : Take a thin wire and stretch it between the two nails about a metre apart. Place a small bit of paper as rider near the middle of the wire and pluck the wire near the rider as shown in Fig. 8.2.

It is observed that the rider flies off as the wire starts vibrating and a sound is heard. After some time when the wire stops vibrating (*i.e.*, when the paper rider placed on the wire, does not fly off), no sound is heard.

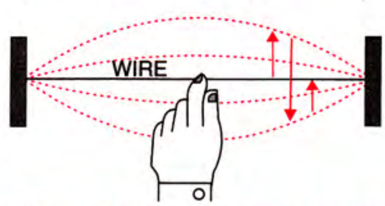


Fig. 8.2 A vibrating wire produces sound

Experiment (3) : Take a tuning fork which is a rectangular rod of steel (or aluminium) bent in the U shape, with a metallic stem at the bend. Strike its one arm on a rubber pad and bring it near a table tennis ball suspended by a thread as shown in Fig. 8.3.

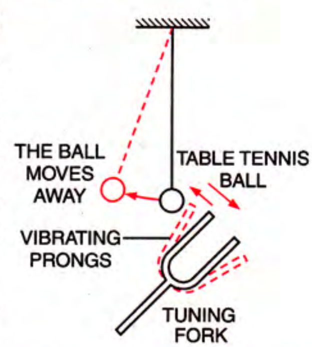


Fig. 8.3 A vibrating tuning fork producing sound

It is noticed that as the arm of vibrating tuning fork is brought close to the ball, it jumps to and fro and sound of the vibrating tuning fork is heard. When its arms stop vibrating, the ball becomes stationary and no sound is heard.

Experiment (4) : Take a drum and beat it. The membrane vibrates which can be felt by touching it and the sound of drum is heard. As the membrane stops vibrating, no sound is heard. This shows that the vibrating drum produces sound.

Experiment (5) : If the string of a sitar (or guitar) is plucked, the string starts vibrating and its sound is heard.

Similarly on blowing a whistle, the air in whistle starts vibrating and a sound is heard.

From the above experiments, it is concluded that sound is produced when a body vibrates. As it stops vibrating, the sound produced by it ceases. Thus

A vibrating body is a source of sound.

Sound is a form of energy : Mechanical energy is required to start vibrations in a body producing sound. The vibrations of body are transmitted in medium in form of waves from that point to the next and so on. These waves on reaching our ears, produce vibrations in the ear drum which are perceived as sound by us. Thus, sound is a form of energy.

8.2 SOUND PROPAGATION REQUIRES A MATERIAL MEDIUM

Sound produced by a vibrating body travels from one place to other through the mechanical vibrations of the medium particles in form of waves. Thus a material medium is required for the propagation of sound. This can easily be demonstrated by the following experiment.

Experiment (Bell jar experiment) : Take an electric bell and an air tight glass bell jar. The electric bell is suspended inside the bell jar. The bell jar is connected to a vacuum pump as shown in Fig. 8.4. As the circuit of electric bell is completed by pressing the key, the hammer of the electric bell is seen to strike the gong repeatedly and the sound of bell is heard.

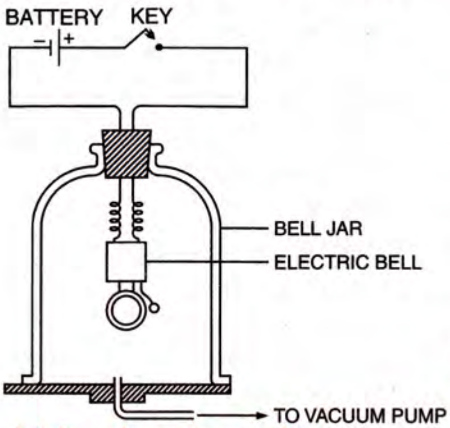


Fig.8.4 Sound requires medium (bell jar experiment)

Now keeping the key pressed, air is gradually withdrawn from the jar by starting the vacuum pump. It is noticed that the loudness of sound goes on decreasing as the air is taken out from the bell jar and finally no sound is heard when the entire air from the jar has been drawn out. *The hammer of electric bell is still seen striking the gong repeatedly* which means that the gong is still vibrating to produce sound (as hammer strikes the gong), but it is not heard.

Explanation : When hammer of the bell hits the gong, sound is produced due to the vibrations of gong which travels through air to the wall of jar. This causes the wall of jar to vibrate due to which the air outside the jar is also set in vibration. Thus sound is heard by us. But when air has been removed from the jar, sound produced due to vibrations of gong could not travel to the wall of jar, so wall could not vibrate and no sound is heard. This clearly demonstrates that sound requires a material medium for its transmission and it cannot travel through vacuum. Thus,

A material medium is necessary for the propagation of sound from one place to another.

Requisites of the medium

The medium required for propagation of sound must possess the following *three* properties :

(i) *The medium must be elastic* so that its particles may come back to their initial positions after displacement on either side.

(ii) *The medium must have inertia* so that its particles may store mechanical energy.

(iii) *The medium should be frictionless* so that there is no loss of energy in propagation of sound through it.

Sound can propagate not only in gases, but also in solids and liquids. Some materials such as air, water, iron etc., can easily transmit sound through them from one place to another. On the other hand, blanket, thick curtains etc., absorb most of the sound incident on them and transmit or reflect only a small fraction of it.

Sound cannot travel in vacuum. On moon, there is no medium, therefore on moon, one can not hear the sound produced by the others.

Note : The light does not require any material medium for its propagation and it can therefore propagate through vacuum as well.

8.3 PROPAGATION OF SOUND IN A MEDIUM

When a source of sound vibrates, it creates a periodic disturbance in the medium near it (*i.e.*, the state of particles of medium changes). The distrubance then travels in the medium in form of waves. This can be understood by the following examples.

Example 1 : Take a thin metal strip. Keeping it vertical, fix its lower end. Push its upper end to one side and then release it. As it vibrates (*i.e.* moves alternately to the right and left) sound is heard.

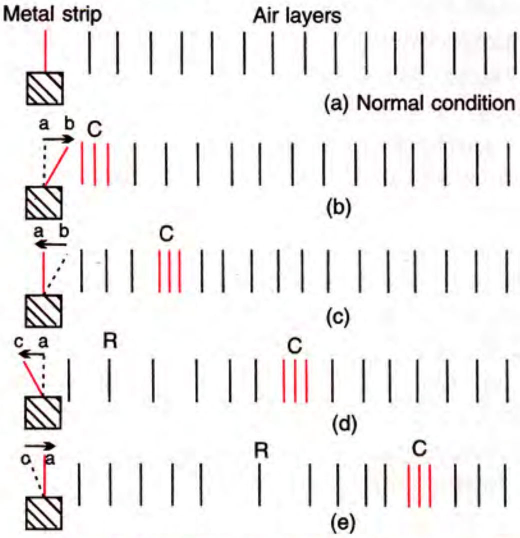


Fig.8.5 Propagation of disturbance in air

Fig. 8.5(a) shows the undisturbed or normal position of the metal strip and the air layers on the right side near the strip in their undisturbed (or normal) position.

As the strip moves to the right from *a* to *b* in Fig. 8.5(b), it pushes the particles of air in layers in front of it. So the particles of air in these layer get closer to each other *i.e.*, air of these layers gets compressed (or *compression* is formed at *C*). The particles of these layers while moving towards right, push and compress the layers next to them, which then compress the next layers and so on. Thus the disturbance moves forward in form of compression. The particles of the medium get displaced, but they do not move along with the compression.

As the metal strip starts returning from *b* to *a* in Fig. 8.5(c) after pushing the particles in front, the particles of air near the strip starts returning back to their mean positions due to the elasticity of the medium.

When the strip moves to the left from *a* to *c* in Fig. 8.5(d), it pushes back the layers of air near it towards its left and thus produces a space of very low pressure on its right side. The air layers on the right side of the strip expand in this region thus forming the rarefied air layers. This region of low pressure is called the *rarefaction R*.

When the strip returns from *c* to its normal position *a* in Fig. 8.5(e), it pushes the rarefaction *R* forward and the air layers near the strip again pass through their mean positions due to the elasticity of the medium.

In this manner, as strip moves to the right and left repeatedly, the compression and rarefaction regions are produced one after the other which carry the disturbance with it with a definite speed depending on the nature of the medium. Gradually due to friction, the strip loses its energy to the medium and the disturbance dies out.

One complete to and fro motion of the strip forms one compression and one rarefaction which together constitute one wave. This wave in which the particles of medium vibrate about their mean positions, in the direction of propogation of sound is called the *longitudinal wave*. Thus *sound travels in air in form of longitudinal waves.* Actually the longitudinal waves can be produced in solids, liquids as well as gases. At compressions, the density and pressure of the medium is maximum, while at rarefaction the density and pressure of the medium is minimum.

Example 2 : In the above example, formation of waves in air could not be seen. The formation of waves can easily be seen on the surface of water. If we drop a piece of stone in the still water of a pond, we hear the sound of stone striking the water surface. Actually a disturbance is produced in water at the point where the stone strikes it. This disturbance spreads in all directions radially outwards in form of circular waves (or ripples) on the surface of water as shown in Fig. 8.6.

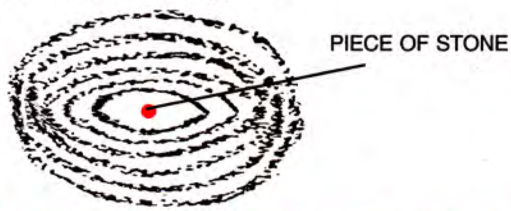


Fig.8.6 Ripples (or waves) formed on the surface of water on dropping a piece of stone in it

Now if we place a piece of cork on the water surface at some distance away from the point where the stone strikes the water, we notice that the *cork does not move ahead, but it moves up and down, while the wave moves ahead.* The reason is that the particles of water (or medium) start vibrating

up and down at the point where the stone strikes. These particles then transfer their energy to the other neighbouring particles and they themselves come back to their mean positions. This process continues and thus the disturbance moves ahead on the water surface in form of waves as shown in Fig. 8.7. The waves die out as soon as the energy imparted by stone gets dissipated. However, it is possible to obtain a continuously travelling wave if a periodic disturbance is produced at the point of striking the stone on the water surface.

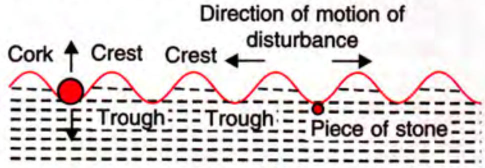


Fig. 8.7 Propagation of disturbance on the surface of water.

The wave in which the particles of medium vibrate about their mean positions, in a direction perpendicular to the direction of propagation of the wave, is called the *transverse wave*. A transverse wave is composed of *crest* and *trough*. The position of maximum upward displacement is called crest, while the position of maximum downward displacement is called trough. The transverse waves can only be produced in solids and on the surface of liquids. They can not be produced inside liquids and in gases.

Characteristics of wave motion : (1) A wave is produced by *the periodic disturbance* at a point in the medium.

(2) Due to propagation of wave in a medium, the particles of medium vibrate about their mean positions (without leaving their positions) and energy is transferred with a constant speed from one place of medium to the other place.

8.4 SOME TERMS RELATED TO WAVE MOTION

(i) Amplitude : *When a wave passes through a medium, the maximum displacement of the particle of medium on either side of its mean position, is called the amplitude of wave.* It is denoted by the letter a. Its S.I. unit is metre (m).

(ii) Time period : *The time taken by a particle of medium to complete its one vibration is called the time period of wave.* It is denoted by the letter T. Its S.I. unit is second (s).

(iii) Frequency : *The number of vibrations made by a particle of medium in one second is called the frequency of wave. It is same as the number of waves passing through a point in one second.* It is denoted by the letter f, n or υ (neu). Its S.I. unit is second^{-1} (symbol s^{-1}) or hertz (symbol Hz).

The frequency f and time period T are related as

$$\boxed{f = \frac{1}{T}} \qquad \text{..... (8.1)*}$$

The frequency of a wave is equal to the frequency of vibration of its source. It is the characterstic of its source which produces the disturbance. It does not depend on the amplitude of vibration or on the nature of medium in which the wave propagates.

(iv) Wavelength : *The distance travelled by the wave in one time period of vibration of particle of the medium, is called its wavelength.* It is denoted by the letter λ (lambda). Its S.I. unit is metre (m). It depends on the medium in which the wave travels.

In a longitudinal wave, the distance between two consecutive compressions or between two consecutive rarefactions is equal to one wavelength, while in a transverse wave, the distance between two consecutive crests or between two consecutive troughs is equal to one wavelength.

(v) Wave velocity : *The distance travelled by a wave in one second is called its wave velocity or wave speed.* It is the speed with which *energy is transferred from one place to the other place by wave motion.* It is not the velocity of an individual particle vibrating about its mean position. It is denoted by the letter V. Its S.I. unit is metre per second (m s^{-1}).

It may be noted that the wave velocity is constant for a given medium. It depends on the elasticity and the density of the medium. It changes when the wave passes from one medium to the other medium.

Displacement-time graph : Fig. 8.8 shows the variation of displacement with time for a particle of the medium *at a given position*, when a wave propagates through the medium. It is called **displacement-time graph**. In Fig. 8.8, the amplitude is represented by the letter a and time period is represented by the letter T. Note that each particle of the medium goes through such motion, not simultaneously, but one after another as the wave moves in the medium.

*** In time T s, number of vibrations = 1**
$\therefore$ In 1 s, number of vibrations = $1/T = f$

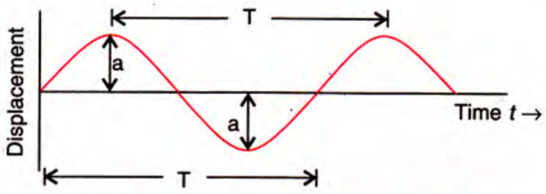


Fig.8.8 Displacement – time graph of a particle of a wave

Displacement-distance graph : Fig. 8.9 shows the displacement-distance graph of a transverse wave *at an instant*. Here amplitude of particles of wave is shown by the letter a and wavelength is shown by the letter λ. The curve shows the displaced positions of particles of medium from their mean positions at an instant when wave propagates through the medium. It is also called snap-shot of a wave.

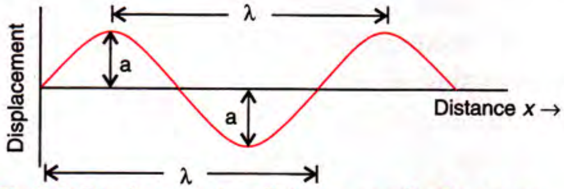


Fig.8.9 Displacement – distance graph of a wave

8.5 RELATIONSHIP BETWEEN THE WAVELENGTH, WAVE VELOCITY AND FREQUENCY

Let velocity of a wave be V, time period T, frequency f and wavelength λ. By the definition of wavelength,

Wavelength λ = Distance travelled by the wave in one time period *i.e.*, in T second
= Wave velocity × Time period
= $V \times T$

or $$\boxed{VT = \lambda} \quad ....(8.2)$$

But $$T = \frac{1}{f}$$

∴ From eqn. (8.2),

$$V \times \left(\frac{1}{f}\right) = \lambda$$

or $$\boxed{V = f\lambda} \quad ...(8.3)$$

Therefore,

Wave velocity = Frequency × Wavelength

8.6 SPEED OF SOUND IN DIFFERENT MEDIA

It is our common experience while standing at some distance from a blacksmith that when a blacksmith strikes his hammer on an iron piece, the sound produced on striking the hammer is heard a short-while after the hammer is seen striking. Similarly the sound of a cracker is heard only a little later than it has exploded (*i.e.*, when flash is seen). This indicates that the sound does not reach us instantaneously but it travels in a medium with a finite speed and it takes some time to reach us from the place where it is produced.

The speed of sound in a medium depends on the following *two* factors :

(i) the elasticity E of the medium, and
(ii) the density ρ of the medium.

The speed of sound in a medium is given by the relation

$$\boxed{V = \sqrt{\frac{E}{\rho}}} \quad ...(8.4)$$

where E is the modulus of elasticity (Young's modulus in case of solids or bulk modulus in case of fluids*) and ρ is the density of the medium.

Newton assumed that when sound travels in a gas, the temperature of gas does not change (*i.e.*, the propagation of sound is an *isothermal change*). For isothermal change, modulus of elasticity is equal to the pressure *i.e.*, $E = P$. Thus from eqn. (8.4), speed of sound in a gas is given as

$$\boxed{V = \sqrt{\frac{P}{\rho}}} \quad ...(8.5)$$

For air at normal temperature and pressure (N.T.P.), $P = 1{\cdot}01 \times 10^5\ \mathrm{N\ m^{-2}}$, $\rho = 1{\cdot}293\ \mathrm{kg\ m^{-3}}$, so V comes out to be $279{\cdot}5\ \mathrm{m\ s^{-1}}$. But experimentally the speed of sound in air is found to be nearly $330\ \mathrm{m\ s^{-1}}$. Thus speed of sound calculated by using eqn. (8.5) is found to be lower than the experimental value.

Later on, the scientist Laplace applied a correction to the above relation. According to Laplace, when sound travels in a gas, during the formation of compression and rarefaction, there is no exchange of heat in the medium *i.e.*, the propagation of sound is an *adiabatic change*. For an adiabatic change, modulus of elasticity $E = \gamma P$ where γ is the ratio of the specific heat at constant pressure to the specific heat at constant volume ($\gamma = C_p / C_v$) and P is the pressure of the gas.

Hence from eqn. (8.4), the speed of sound in a gas is given as

$$\boxed{V = \sqrt{\frac{\gamma P}{\rho}}} \quad ...(8.6)$$

The value of γ depends on the nature of the medium. For air, γ is 1·4.

* **Fluids include liquids and gases.**

This modified formula (eqn. 8.6) gave the correct value of the speed of sound. At N.T.P. in air, taking $\gamma = 1{\cdot}4$, $P = 1{\cdot}01 \times 10^5$ N m^{-2} and $\rho = 1{\cdot}293$ kg m^{-3}. V comes out to be nearly 330·7 m s^{-1} which agrees with the experimental value.

The speed of sound is different in different media. The speed of sound is more in solids, less in liquids and least in gases (since solids are much more elastic than the liquids and gases). The speed of sound is nearly 5100 m s^{-1} in steel, 1450 m s^{-1} in water and 330 m s^{-1} in air at 0°C.

Table below gives the speed of sound in different media at 0°C.

Speed of sound in some media

Medium	Speed of sound (in m s^{-1})
Gases	
Air	330
Carbon dioxide	260
Hydrogen	1270
Liquids	
Alcohol	1210
Turpentine	1325
Water	1450
Solids	
Copper	3560
Steel	5100
Glass	5500
Granite	6000

Examples showing that the speed of sound in steel is more than that in air

(1) If sound is produced at one end of a very long steel bar, two sounds are heard at the other end. One which reaches first, is propagated through steel and the other which is heard later, is through air.

(2) A person living near the railway track often presses his ear against the steel rail to guess whether a train is coming or not. The reason is that the vibrations produced by the moving wheels of train, travel much faster through the steel rail than through air. So sound is heard through track much before it is heard through air. Thus the person by hearing sound through the steel rail gets an indication of coming of train well before its sound is heard..

8.7 FACTORS AFFECTING THE SPEED OF SOUND IN A GAS

The speed of sound in a gas is affected by the change in (i) density, (ii) temperature, (iii) humidity, and (iv) direction of wind.

(i) *Effect of density* : From relation $V = \sqrt{\frac{\gamma P}{\rho}}$, it is clear that $V \propto \frac{1}{\sqrt{\rho}}$ *i.e.*, *the speed of sound is inversely proportional to the square root of density of the gas.* The density of oxygen is 16 times the density of hydrogen, therefore the speed of sound in hydrogen is four times the speed of sound in oxygen*.

(ii) *Effect of temperature* : *The speed of sound in a gas increases with the increase in temperature of the gas.* The reason is that with the increase in temperature, the density of gas decreases and consequently the speed of sound increases. In fact, the speed of sound is directly proportional to the square root of temperature of the medium *i.e.*, $V \propto \sqrt{T}$ where T is the temperature of the gas on the Kelvin scale.

The speed of sound in air increases by about 0·61 m s^{-1} (or 61 cm per second) for each degree celsius rise in temperature (provided that the rise in temperature is not very large). *i.e.*,

$$\boxed{V_t = V_0 + 0{\cdot}61\, t} \qquad \ldots(8.7)$$

Example : The speed of sound in the dry still air at 0°C is 330 m s^{-1}. At 25°C, the speed of sound in this air will be

$V_{25} = V_0 + 0{\cdot}61\, t = 330 + 0{\cdot}61 \times 25 = 345{\cdot}25$ m s^{-1}.

(iii) *Effect of humidity* : *The speed of sound in air increases with the increase in humidity in air.* The density of water vapour is about $\frac{5}{8}$th times the density of dry air at ordinary temperature, therefore the increase of moisture in air tends to decrease the density of air. Hence the speed of sound in the humid air is greater than the speed of sound in dry air. In other words, *the sound travels faster in humid air than in dry air.*

(iv) *Effect of direction of wind* : *The speed of sound increases or decreases according to the direction of travel of wind.* If wind is blowing in the direction of propagation of sound, the speed of sound increases, while if it is blowing

* $\frac{\text{Velocity of sound in hydrogen}}{\text{Velocity of sound in oxygen}} = \sqrt{\frac{\text{Density of oxygen}}{\text{Density of hydrogen}}}$

or $\frac{V_{H_2}}{V_{O_2}} = \sqrt{\frac{16}{1}} = 4$

in a direction opposite to that of sound, the speed of sound decreases.

If V is the speed of sound in still air and W is the speed of wind, the speed of sound becomes $V + W$ when wind blows in the direction of travel of sound and the speed of sound becomes $V - W$ when wind blows in the direction opposite to the direction of travel of sound.

Example : The sound of a distant music is quickly and loudly heard if it is coming with the wind. On the other hand, it is difficult to hear if the wind blows in opposite direction.

8.8 FACTORS NOT AFFECTING THE SPEED OF SOUND IN A GAS

The speed of sound in a gas is not affected by the change in (i) pressure, (ii) amplitude of wave, and (iii) wavelength or frequency of wave.

(i) *Effect of pressure* : *The speed of sound in a gas is independent of pressure.* In the formula $V = \sqrt{\frac{\gamma P}{\rho}}$, the ratio $\frac{P}{\rho}$ remains unchanged with the change in pressure. When pressure increases, volume decreases, but mass remains unchanged, so density increases, such that the ratio P/ρ remains constant. For example, if pressure P of a gas is doubled, volume becomes half, so density ρ gets doubled (mass is constant). As a result, the ratio P/ρ does not change. Thus, the speed of sound in a gas is independent of pressure.

(ii) *Effect of amplitude of wave* : *The speed of sound does not depend on the amplitude of sound wave.*

(iii) *Effect of wavelength (or frequency) of wave* : *The speed of sound does not depend on the wavelength (or frequency) of sound wave.*

8.9 COMPARISON OF SPEED OF SOUND WITH SPEED OF LIGHT

There are the following *four* points of distinction between the propagation of sound and light waves.

(1) The light waves can travel in vacuum, but the sound waves can not travel in vacuum.

(2) Ths speed of light waves is 3×10^8 m s^{-1} in air which is about a million times greater than the speed of sound waves in air (*i.e.*, 330 m s^{-1} at 0°C).

(3) The speed of light waves decreases in an optically denser medium (speed of light in water is $2{\cdot}25 \times 10^8$ m s^{-1}, in glass is 2×10^8 m s^{-1}), while the speed of sound waves is more in solids, less in liquids and still less in gases (speed of sound in steel is nearly 5100 m s^{-1}, in water is nearly 1450 m s^{-1} and in air is nearly 330 m s^{-1}).

(4) The light waves are transverse electromagnetic waves while the sound waves in air are the longitudinal mechanical waves.

Consequences of the large difference in the speed of sound and that of light

(1) **Thunder and lightning :** *In thunder, light is seen much earlier than the sound of thunder is heard, although they are produced simultaneously.* The reason is that light takes almost negligible time in comparison to sound in reaching us from the place of thunder because speed of light is much more (= 3×10^8 m s^{-1}) than the speed of sound (= 330 m s^{-1}).

(2) When the starter in an athletic event fires a gun, a spectator sitting at a distance hears the sound of fire a little later while the smoke is instantaneously seen. The reason is that $V_{light} >> V_{sound}$.

(3) The spectators watching the cricket game hear the sound of stroke a little later than the batsman is seen actually making it. The reason is that $V_{light} >> V_{sound}$.

8.10 EXPERIMENTAL DETERMINATION OF SPEED OF SOUND IN AIR

The fact that light travels in air about a million times faster than sound, can be used to determine the speed of sound in air.

Experiment : Choose two places A and B at high altitudes facing each other, at a known distance d apart (say, about 1 km), in still air. The distance d is noted. At each place, there is an observer with a gun and a stop watch. First the observer at place A fires the gun, while the observer at place B starts his stop watch immidiately on seeing the flash of fire at A and stops it when he hears the sound of fire. The observer at B by his watch thus finds the time interval t_1 taken by the sound to travel from A to B.

Now the observer at place B fires the gun. The observer at place A starts his stop watch when he sees the flash of fire at B and stops it when he hears the sound of fire. Thus the observer A by his

watch finds the time interval t_2 taken by sound to travel from B to A.

The average of the two time intervals is $t = \frac{t_1 + t_2}{2}$. This is the time taken by sound to travel the distance d between the places A and B. The speed of sound is then calculated by using the formula

$$V = \frac{\text{Distance}}{\text{Time}} = \frac{d}{t} \text{ m s}^{-1} \quad ...(8.8)$$

Note : In this experiment, we measure the time interval two times, first for sound to travel from place A to place B and then from place B to place A so as to eliminate the error arising due to flow of wind. However, the speed of sound so determined is not still very accurate because of the personal error of the two observers and the variation in temperature and humidity of air in between the places A and B.

EXAMPLES

1. A bat can hear sound of frequencies up to 120 kHz. Determine the minimum wavelength of sound which it can hear. Take speed of sound in air to be 344 m s^{-1}.

Given, $f = 120 \text{ kHz} = 120 \times 10^3 \text{ Hz}$, $V = 344 \text{ m s}^{-1}$.

From relation $V = f\lambda$,

$$\text{Wavelength } \lambda = \frac{V}{f} = \frac{344}{120 \times 10^3}$$

$$= \mathbf{2{\cdot}87 \times 10^{-3} \text{ m}} \text{ (or } \mathbf{2{\cdot}87 \text{ mm}})$$

i.e., the bat can hear sound of minimum wavelength 2·87 mm.

2. Ocean waves of time period 10 s have wave velocity 15 m s^{-1}. Find : (i) the wavelength of these waves, (ii) the horizontal distance between a wave crest and its adjoining wave trough.

Given, $T = 10$ s, $V = 15 \text{ m s}^{-1}$

(i) From relation $V = \frac{\lambda}{T}$,

Wavelength of wave $\lambda = V \times T$

or $\lambda = 15 \times 10 = \mathbf{150 \text{ m}}$

(ii) The distance between a wave crest and its adjoining wave trough

$$= \frac{\lambda}{2} = \frac{1}{2} \times 150 \text{ m} = \mathbf{75 \text{ m}}.$$

3. A wave pulse of frequency 200 Hz, on a string moves a distance 8 m in 0·05 s. Calculate : (a) the velocity of pulse, and (b) the wavelength of wave on string.

Given, $d = 8$ m, $t = 0{\cdot}05$ s, $f = 200$ Hz

(a) The velocity of pulse $V = \frac{\text{Distance moved } d}{\text{Time taken } t}$,

or $V = \frac{8 \text{ m}}{0{\cdot}05 \text{ s}} = \mathbf{160 \text{ m s}^{-1}}$

(b) Wave velocity on string V

= velocity of wave pulse on it = 160 m s^{-1}

From relation $V = f\lambda$,

$$\text{Wavelength of wave } \lambda = \frac{V}{f} = \frac{160}{200} = \mathbf{0{\cdot}8 \text{ m}}.$$

4. Compare approximately the speed of sound in air and steel.

The speed of sound in air is nearly 330 m s^{-1} and in steel is nearly 5100 m s^{-1}. Thus, the ratio of speed of sound in air and steel is

$$\frac{\text{Speed of sound in air}}{\text{Speed of sound in steel}} = \frac{330 \text{ m s}^{-1}}{5100 \text{ m s}^{-1}} = \frac{\mathbf{1}}{\mathbf{15}} \textbf{ nearly}.$$

5. The smoke from the gun barrel is seen 2 second before the explosion is heard. If the speed of sound in air is 340 m s^{-1}, calculate the distance of observer from gun. State the approximation used.

Given : Speed of sound = 340 m s^{-1}, time = 2 s

$$\text{Speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

$\therefore$ Distance = speed × time

$= 340 \times 2 = \mathbf{680 \text{ m}}$.

Approximation :

The speed of light ($= 3 \times 10^8 \text{ m s}^{-1}$) is much larger in comparison to the speed of sound ($= 340 \text{ m s}^{-1}$), therefore we can assume that the light takes negligible time and sound takes 2 s to reach the observer.

6. The speed of sound in air is 330 m s^{-1} and in water is 1650 m s^{-1}. It takes 2 s for sound to

reach a certain distance from the source placed in air. (a) Find the distance. (b) How much time will it take for sound to reach the same distance when the source is in water ?

(a) Given, in air $V = 330 \text{ m s}^{-1}$, $t = 2 \text{ s}$

From relation $V = \frac{d}{t}$

Distance travelled by sound in air,

$$d = V \times t = 330 \times 2 = \mathbf{660 \text{ m}}$$

(b) In water, $V = 1650 \text{ m s}^{-1}$, $d = 660 \text{ m}$

∴ Time taken by sound to travel the distance d in water will be

$$t = \frac{d}{V} = \frac{660 \text{ m}}{1650 \text{ m s}^{-1}} = \mathbf{0{\cdot}4 \text{ s.}}$$

EXERCISE 8 (A)

1. What causes sound ?

Ans. Sound is caused due to vibrations of a body.

2. What is sound ? How is it produced ?

3. Complete the following sentence :

Sound is produced by a .... body.

Ans. Vibrating

4. Describe a simple experiment which demonstrates that the sound produced by a tuning fork is due to vibrations of its arms.

5. Describe in brief, with the aid of a labelled diagram, an experiment to demonstrate that a material medium is necessary for the propagation of sound.

6. There is no atmosphere on moon. Can you hear each other on the moon's surface ? **Ans.** No.

7. State *three* characteristics of the medium required for propagation of sound ?

8. Explain with an example, the propagation of sound in a medium.

9. Choose the correct word/words to complete the following sentence :

When sound travels in a medium ...... (the particles of the medium, the source, the disturbance, the medium) travels in form of a wave. **Ans.** the disturbance

10. Name the *two* kinds of waves in form of which sound travels in a medium.

11. What is a longitudinal wave ? In which medium: solid, liquid or gas, can it be produced ?

12. What is a transverse wave ? In which medium: solid, liquid or gas, can it be produced ?

13. Explain meaning of the terms compression and rarefaction in relation to a longitudnal wave.

14. Explain the terms crest and trough in relation to a transverse wave.

15. Describe an experiment to show that in wave motion, only energy is transferred, but particles of medium do not leave their position.

16. Define the term amplitude of a wave. Write its S.I. unit.

17. What do you mean by the term frequency of a wave ? State its S.I. unit.

18. How is the frequency of a wave related to its time period ? **Ans.** Frequency = 1/time period

19. Define the term wave velocity. Write its S.I. unit.

20. Draw displacement-time graph of a wave and show on it the amplitude and time period of wave.

21. Draw a displacement-distance graph of a wave and mark on it, the amplitude of wave by the letter a and wavelength of wave by the letter λ.

22. How are the wave velocity V, frequency f and wavelength λ of a wave related ? Derive the relationship.

23. State *two* properties of medium on which the speed of sound in it depends.

Ans. (i) Elasticity (ii) density.

24. Arrange the speed of sound in gases V_g, solids V_s and liquids V_l in an ascending order.

Ans. $V_g < V_l < V_s$

25. State the speed of (i) light and (ii) sound in air ?

Ans. (i) Speed of light = $3 \times 10^8 \text{ m s}^{-1}$
(ii) Speed of sound = 330 m s^{-1}.

26. Compare approximately the speed of sound in air, water and steel. **Ans.** 1 : 4 : 15

27. Answer the following :

(i) Can sound travel in vacuum ?

(ii) How does the speed of sound differ in different media ?

Ans. (i) No (ii) Speed of sound is maximum in solids, less in liquids and least in gases.

28. Flash of lightning reaches us earlier than the sound of thunder. Explain the reason.

Ans. Light travels much faster than sound

29. If you place your ear close to an iron railing which is tapped some distance away, you hear the sound twice. Explain why ?

Ans. Sound travels in iron faster than in air, so first the sound through iron rail is heard and then the sound through air is heard.

30. The sound of an explosion on the surface of a lake is heard by a boat man 100 m away and by a diver 100 m below the point of explosion.
(i) Who would hear the sound first : boat man or diver ?
(ii) Give a reason for your answer in part (i).
(iii) If sound takes time t to reach the boat man, how much time approximately does it take to reach the diver ?
Ans. (i) diver (ii) sound travels faster in water than in air (iii) 0·25 t.

31. How do the following factors affect, if at all, the speed of sound in air :
(i) frequency of sound, (ii) temperature of air, (iii) pressure of air, (iv) moisture in air ?
Ans. (i) No effect (ii) Speed of sound increases with the increase in temperature (iii) No effect (iv) Speed of sound increases with the increase of moisture in air.

32. How does the speed of sound change with change in (i) amplitude and (ii) wavelength, of sound wave ? **Ans.** (i) No change (ii) No change.

33. In which medium the speed of sound is more : humid air or dry air ? Give a reason to your answer.
Ans. In humid air. **Reason :** Density of air decreases with the increase of moisture and $V \propto \frac{1}{\sqrt{\rho}}$.

34. How does the speed of sound in air vary with temperature ?
Ans. The speed of sound increases by 0·61 m s^{-1} for each 1°C rise in temperature.

35. Describe a simple experiment to determine the speed of sound in air. What approximation is made in the method described by you ?

36. Complete the following sentences :
(a) Sound can not travel through ....,but it requires a ....
(b) When sound travels in a medium, the particles of medium .... but the disturbance ....
(c) A longitudinal wave is composed of compression and ....
(d) A transverse wave is composed of crest and ....
(e) Wave velocity = ... × wavelength.
Ans. (a) vacuum, medium (b) do not move, moves (c) rarefaction (d) trough (e) frequency.

Multiple choice type :

1. The correct statement is :
(a) Sound and light both require medium for propagation
(b) Sound can travel in vacuum, but light can not
(c) Sound needs medium, but light does not need medium for its propogation
(d) Sound and light both can travel in vacuum.
Ans. (c) Sound needs medium, but light does not need medium for its propogation.

2. Sound in air propagates in form of :
(a) longitudinal wave
(b) transverse wave
(c) both longitudinal and transverse waves
(d) neither longitudinal nor transverse wave.
Ans. (a) longitudinal wave

3. The speed of sound in air at 0°C is nearly :
(a) 1450 m s^{-1} (b) 450 m s^{-1}
(c) 5100 m s^{-1} (d) 330 m s^{-1}
Ans. (d) 330 m s^{-1}

4. The speed of light in air is :
(a) 3×10^8 m s^{-1} (b) 330 m s^{-1}
(c) 5100 m s^{-1} (d) 3×10^{10} m s^{-1}
Ans. (a) 3×10^8 m s^{-1}

Numericals :

1. The heart of a man beats 75 times a minute. What is its (a) frequency and (b) time period ?
Ans. (a) 1·25 s^{-1}, (b) 0·8 s

2. The time period of a simple pendulum is 2 s. Find its frequency. **Ans.** 0·5 Hz

3. The separation between two consecutive crests in a transverse wave is 100 m. If wave velocity is 20 m s^{-1}, find the frequency of wave.
Ans. 0·2 Hz

4. A longitudinal wave travels at a speed of 0·3 m s^{-1} and the frequency of wave is 20 Hz. Find the separation between the two consecutive compressions.
Ans. $1 \cdot 5 \times 10^{-2}$ m (or 1·5 cm)

5. A source of wave produces 40 crests and 40 troughs in 0·4 s. What is the frequency of the wave ? **Ans.** 100 Hz

6. An observer A fires a gun and antoher observer B at a distance 1650 m away from A hears its sound. If the speed of sound is 330 m s^{-1}, find the time when B will hear the sound after firing by A.
Ans. 5 s

7. The time interval between a lightning flash and the first sound of thunder is 5 s. If the speed of sound in air is 330 m s^{-1}, find the distance of flash from the observer. **Ans.** 1650 m

8. A boy fires a gun and another boy at a distance hears the sound of fire 2·5 s after seeing the flash. If speed of sound in air is 340 m s^{-1}, find distance between the boys. **Ans.** 850 m

9. An observer sitting in line of two tanks, watches the flashes of two tanks firing at each other at the same time, but he hears the sounds of two shots 2 s and 3·5 s after seeing the flashes. If distance between the two tanks is 510 m, find the speed of sound. **Ans.** 340 m s^{-1}

10. How long will sound take to travel in (a) an iron rail and (b) air, both 3·3 km in length ? Take speed of sound in air to be 330 m s^{-1} and in iron to be 5280 m s^{-1}. **Ans.** (a) 0·625 s, (b) 10 s

11. Assuming the speed of sound in air equal to 340 m s^{-1} and in water equal to 1360 m s^{-1}, find the time taken to travel a distance 1700 m by sound in (i) air and (ii) water. **Ans.** (i) 5 s (ii) 1·25 s

(B) INFRASONIC, SONIC AND ULTRASONIC FREQUENCIES

8.11 INFRASONIC, SONIC AND ULTRASONIC FREQUENCES

The human ear is able to hear sound in a frequency range of about 20 Hz to 20,000 Hz (or 20 kHz) *i.e., the audible range of frequency is* 20 Hz *to* 20 kHz. We can not hear sounds of frequencies less than 20 Hz or more than 20 kHz. Actually the audible range of frequency varies from person to person and it also varies with the age of the person. The audible range of frequency of a person decreases as he gets older since his ears lose the hearing sensitivity to the high frequencies. Children can hear sounds of some what higher frequencies say up to 30 kHz, while an old person can hear sound only up to frequencies 12 kHz. Hence the audible range of frequency for an average person is considered to be from 20 Hz to 20 kHz. Even in the audible range, the human ear is not equally sensitive to all frequencies. *The human ear is most sensitive in the range* 2000 Hz *to* 3000 Hz, *where it can hear even a very feeble sound.*

The sound of frequencies in the range 20 Hz to 20 kHz is called the *sonic* or *audible sound*; the sound of frequency less than 20 Hz is known as *infrasonic sound* (or simply *infrasonic*), while the sound of frequency greater than 20 kHz is known as *ultrasound* (or *ultrasonic*).

Animals can produce and hear sounds of frequencies below 20 Hz as well as above 20 kHz. Different animals have different ranges of audible frequencies. Elephants and whales can produce infrasonic sounds of frequencies less than 20 Hz. Some fishes can hear sounds of frequencies in the range of 1 Hz to 25 Hz. Some animals can produce ultrasonic sounds and communicate in them. A dog can hear sounds of frequencies up to nearly 50 kHz, a bat up to about 100 kHz, while Dolphins can hear sounds of even higher frequencies up to 150 kHz.

Frequency ranges for hearing and speaking by human and animals

Object	Frequency range of hearing and speaking
1. Bat	10 Hz – 100 kHz
2. Cat	80 Hz – 60 kHz
3. Dog	20 Hz – 50 kHz
4. Dolphins	200 Hz – 150 kHz
5. Grasshopper	90 Hz – 1·0 kHz
6. Human	20 Hz – 20 kHz

8.12 ULTRASOUND AND ITS APPLICATIONS

We have read that the sound of frequencies above 20,000 Hz, is called the ultrasound. Ultrasound can travel quite freely in solids and liquids, but in gases its intensity falls. In a medium, it travels with the same speed with which the audible sound travels. In air, the speed of ultrasound is 330 m s^{-1}.

Properties of ultrasound

Ultrasound has all properties similar to that of ordinary sound, but because of high frequencies, ultrasound has the following *two* additional properties which the audible sound does not possess.

(i) The energy carried by ultrasound is very high.

(ii) The ultrasound can travel along a well defined straight path. It does not bend appreciably at the edges of an obstacle because of its small wavelength (*i.e.*, it has high directivity).

The above two properties of ultrasound makes it very useful to us for many purposes.

Applications of ultrasound

Few applications of ultrasound are given below.

(1) Bats avoid obstacles in their path by producing and hearing the ultrasound. They produce ultrasound which returns after striking an obstacle in their way. By hearing the reflected

sound, they can judge the direction where the obstacle is in their way and from the time interval (when they produce ultrasound and then receive them back), they can judge the distance of the obstacle.

(2) Ultrasound is used for drilling holes or making cuts of desired shape in materials like glass.

(3) For cleaning the minute objects such as the parts of watches and electronic components, ultrasound is used. The objects are placed in a cleaning solution and the ultrasonic waves are sent into the solution. This causes high frequency vibrations in the solution and makes the cleaning easier.

(4) For detection of defects in metals, ultrasound is used. Ultrasound will pass through the object if there is no defect (such as crack or cavity), in the object. But if there is some defect, a part of ultrasound will get reflected back.

(5) For imaging the human organs, ultrasound is widely used. *Ultrasonography* is used to obtain the images of patient's organs (such as liver, gall bladder, uterus *etc*.). It helps to detect stones, tumors *etc*. in them. *Echo cardiography* is used to obtain the image of the heart.

(6) Ultrasound is used in surgery to remove cataract and in kidneys to break the small stones into fine grains.

(7) In SONAR (abbreviated form of sonographic navigation and ranging) to detect and find the distance of objects under water, ultrasound is used.

Difference between ultrasonic and supersonic

The word ultrasonic is used for ultrasound (*i.e.*, sound of frequency above 20 kHz), while supersonic is used for object which travels with a speed greater than the speed of sound in air (*i.e.*, 330 m s^{-1}) *e.g.* concord jet planes and fighter planes.

EXERCISE 8 (B)

1. What do you mean by the audible range of frequency ?
   Ans. The range of frequency within which the sound can be heard by a human being is called the audible range of frequency.
2. What is the audible range of frequency for human ? **Ans.** 20 Hz to 20 kHz
3. For which range of frequencies, human ears are most sensitive ? **Ans.** 2000 Hz to 3000 Hz
4. Which has the higher frequency – ultrasonic sound or infrasonic sound ? **Ans.** Ultrasonic sound.
5. Complete the following sentences :
   (a) An average person can hear sound of frequencies in the range .... to ....
   (b) Ultrasound is of frequency ....
   (c) Infrasonic sound is of frequency ....
   (d) Bats can produce and hear .... sound.
   (e) Elephants produce .... sound.

Ans. (a) 20 Hz, 20 kHz (b) above 20 kHz (c) below 20 Hz (d) ultrasonic (e) infrasonic.

6. Name the sounds of the frequencies given below:
   (a) 10 Hz (b) 100 Hz (c) 1000 Hz (d) 40 kHz
   Ans. (a) infrasonic (b) audible (c) audible (d) ultrasonic.
7. Can you hear the sound produced due to vibrations of a seconds' pendulum ? Give reason.
   Ans. No. **Reason :** The frequency of sound produced due to vibrations of seconds' pendulum is 0·5 Hz which is infrasonic sound.
8. What is ultrasound ?
   Ans. Sound of frequency above 20 kHz.
9. State the approximate speed of ultrasound in air.
   Ans. 330 m s^{-1}
10. State *two* properties of ultrasound that make it useful to us.
    Ans. (i) High energy content, (ii) high directivity.
11. Explain how do bats locate the obstacles and prey in their way.
12. State *two* applications of ultrasound.

Multiple choice type :

1. A man can hear the sound of frequency :
   (a) 1 Hz (b) 1000 Hz
   (c) 200 kHz (d) 5 MHz **Ans.** (b) 1000 Hz
2. The properties of ultrasound that make it useful, are :
   (a) high power and high speed
   (b) high power and good directivity
   (c) high frequency and high speed
   (d) high frequency and bending around the objects.
   Ans. (b) high power and good directivity
3. Sonar makes use of :
   (a) infrasonic sound (b) ultrasound
   (c) ordinary sound (d) light.
   Ans. (b) ultrasound

9 CURRENT ELECTRICITY

Syllabus :

(i) *Simple electric circuit using an electric cell and a bulb to introduce the idea of current (including its relationship to charge); potential difference; insulators and conductors; closed and open circuits; direction of current (electron flow and conventional).*

Scope – Current electricity : brief introduction of sources of direct current — cells, accumulators (construction, working and equations excluded); electric current as the rate of flow of electric charge (direction of current — conventional and electronic), symbols used in circuit diagrams. Detection of current by galvanometer or ammeter (functioning of meters not to be introduced). Idea of electric circuit by using cell, key, resistance wire/resistance box/rheostat qualitatively; elementary idea about work done in transferring charge through a conductor wire; potential difference $V = W/q$; resistance R from Ohm's law $V/I = R$; insulators and conductors. (No derivation of formula) simple numerical problems.

(ii) *Efficient use of energy.*

Scope – Social initiatives : improving efficiency of existing technologies and introducing new eco-friendly technologies, creating awareness and building trends of sensitive use of resources and products e.g. reduced use of electricity.

(A) ELECTRIC CURRENT

9.1 SOURCES OF DIRECT CURRENT

We are familiar with cells used in a torch to light up its bulb. *The cells are the source of direct current*. They provide direct current (abbreviated as d.c.) to the bulb. The current flows from the positive terminal of cell to its negative terminal* through the bulb of the torch (Fig. 9.1). The magnitude of current given by a cell remains constant for a sufficiently long time. When the cell gets discharged, it stops giving current and becomes useless. Thus we can define direct current (d.c.) as follows :

Direct current (d.c.) is a current of constant magnitude flowing in one direction.

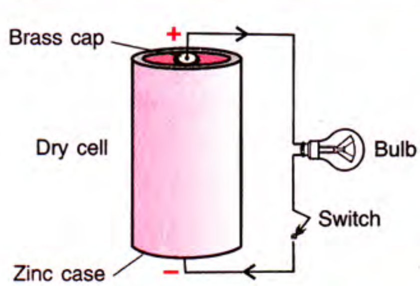


Fig 9.1 A dry cell used to light up a bulb

* In a dry cell, brass cap projecting out at the centre acts as the positive terminal of cell and base of zinc case acts as the negative terminal.

In a cell, chemical energy changes into the electrical energy when it sends current in a circuit. A cell basically consists of two conducting rods, called the *electrodes*, at some separation placed immersed in a solution (or jelly), called the *electrolyte*, kept in a vessel.

Kinds of cells : The cells are of *two* kinds :

(1) The primary cells, and

(2) The secondary cells or accumulators.

(1) Primary cells : These cells provide current as a result of *irreversible* chemical reaction. The cells are discarded after use when entire chemical energy in them has converted into the electrical energy. Thus these are *'use and throw'* type of cells and cannot be recharged. Depending upon the material of electrodes and electrolyte, we have different types of primary cells *e.g.* simple voltaic cell, Leclanche cell, Daniel cell, dry cell, *etc.*

(2) Secondary cells or accumulators : Secondary cells also provide current as a result of chemical reaction. In these cells, chemical reaction is *reversible* and so they can be recharged after use. After taking the electrolyte and electrodes in a vessel, the cell is first charged by connecting it to a direct current source. During

charging, the electrical energy changes into the chemical energy and gets stored in the cell. When cell is used to send current in a circuit, the chemical energy changes into the electrical energy. These cells can thus be used for a very long period because they can be recharged again and again. Lead (or acid) accumulator and Ni-Fe (or alkali) accumulator are the two types of secondary cells commonly used to provide low as well as high current. We use lead accumulator as battery in a car as it is capable of giving high current. Low current rechargeable cells are widely used in toys and mobile phones. These cells are also called the storage cells.

Difference between the primary cell and secondary cell

Primary cell	Secondary cell
1. Chemical reaction is irreversible.	1. Chemical reaction is reversible.
2. Chemical energy is converted into electrical energy when current is drawn from it.	2. Electrical energy converts into chemical energy when current is passed in it (*i.e.*, during charging), while chemical energy converts into electrical energy when current is drawn from it (*i.e.*, during discharging).
3. It can not be recharged.	3. It can be recharged.
4. Its internal resistance is high.	4. Its internal resistance is low.
5. It is capable of giving weak current only.	5. It can provide low as well as high current.
6. It is light and cheap.	6. It is heavy and costly.
Examples : Simple voltaic cell, Leclanche cell, Daniel cell, dry cell.	*Examples* : Lead (or acid) accumulator, Ni-Fe (or alkali) accumulator, Li-H battery.

9.2 ELECTRIC CURRENT (AS RATE OF FLOW OF ELECTRIC CHARGE)

We have read that when two bodies are rubbed together, they get charged due to transfer of electrons from one body to the other. The body gaining electrons becomes negatively charged while the body loosing electrons gets positively charged. A positively charged body has a deficit of electrons, while a negatively charged body has an excess of electrons. The charges can be made to flow between them by suitable arrangements. For example, if two charged bodies are joined by a metallic wire, the electrons flow from the body having more electrons, to the body having less electrons. The flow of electrons constitutes an electric current. Thus current flows due to motion of charges. *The rate of flow of charge gives the magnitude of current.* Thus

> *Current is the rate of flow of charge across a cross-section normal to the direction of flow of current.*

If charge Q flows through the cross-section of a conductor in time t, then

$$\boxed{\text{Current } (I) = \frac{\text{Charge}(Q)}{\text{time}(t)}} \qquad \ldots(9.1)$$

*The current is a **scalar** quantity.*

In metals (or conductors), current flows due to the movement of electrons, while in electrolytes, current flows due to the movement of both, the positive and negative ions. An electron carries a negative charge equal to $-e$, where $e = 1{\cdot}6 \times 10^{-19}$ coulomb is the electronic charge.

If n electrons pass through the cross section of a conductor in time t, then

$$\boxed{\begin{aligned} &\text{Total charge passed } Q = n \times e \\ &\text{and current in conductor } I = \frac{Q}{t} = \frac{ne}{t} \end{aligned}} \qquad ..(9.2)$$

Note : In an electrolyte, the current flows due to the movement of both the positive ions (*i.e.*, cations) and negative ions (*i.e.*, anions). In one second, if n_1 positive ions each carrying a charge q_1 move in one direction and n_2 negative ions each carrying a charge q_2 move in opposite direction, the total current will be $I = n_1(+q_1) - n_2(-q_2) = (n_1q_1 + n_2q_2)$, because direction of current is taken positive in the direction of flow of positive ions, and negative in the direction of flow of negative ions.

Direction of current (conventional and electronic)

Conventionally, the direction of current is taken positive in the direction of flow of positive charge. Therefore, conventionally, the current will be negative in the direction of flow of electrons. The rate of flow of electrons in a direction is called the electronic current in that direction. *The conventional current (or simply current) is in a direction opposite to the direction of motion of*

electrons. The magnitude of conventional current is the rate of flow of total charge across the given cross-section.

Unit of current : From relation $I = \frac{Q}{t}$

$$\text{Unit of current} = \frac{\text{Unit of charge}}{\text{Unit of time}}.$$

The S.I. unit of charge is coulomb and S.I. unit of time is second, so the S.I. unit of current is coulomb per second which is called ***ampere***. It is denoted by the symbol A. Thus.

$$\boxed{1 \text{ ampere (A)} = \frac{1 \text{ coulomb (C)}}{1 \text{ second (s)}}} \quad ...(9.3)$$

Thus current is 1 A, if the rate of flow of charge is 1 coulomb per second. Since 1 coulomb of charge is carried by $\frac{1}{1 \cdot 6 \times 10^{-19}} = 6 \cdot 25 \times 10^{18}$ electrons, therefore if 1 ampere current flows through a conductor, it means that $6 \cdot 25 \times 10^{18}$ electrons pass in 1 second across that cross section of conductor.

Note : Weak current is measured in units milli-ampere (mA) and micro-ampere (μA), where

1 milli-ampere (mA) = 10^{-3} ampere (A), and
1 micro-ampere (μA) = 10^{-6} ampere (A).

9.3 SYMBOLS USED IN CIRCUIT DIAGRAMS

An electric circuit has different electric components connected to a current source. Fig. 9.2 shows some of the electric components which are used in an electric circuit in the laboratory.

The symbols and functions of various electric components are given below.

(1) Source of current : There are *two* types of current sources : (i) alternating current* (a.c.) source such as mains in our house and a.c. generator, and (ii) direct current (d.c.) source such as a cell or a battery. The purpose of source of current is to supply electric current in a circuit. In laboratory, Leclanche cell

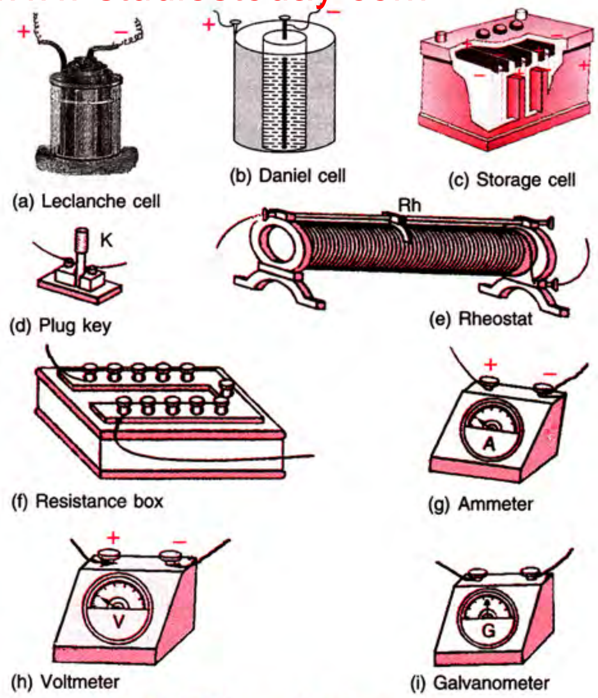


Fig. 9.2 Different electric components

[Fig. 9.2(a)], Daniel cell [Fig. 9.2(b)] and lead accumulator (storage cell) [Fig. 9.2(c)] are used.

A *d.c. sources* (cell) is represented by two vertical lines of unequal lengths. The longer one is marked '+' to represent anode, while the shorter is marked '–' to represent cathode [Fig. 9.3 (a)]. When current is drawn from a cell, it flows from the positive terminal to the negative terminal through the external circuit and from the negative terminal to the positive terminal inside the cell through its electrolyte so as to maintain a continuous flow.

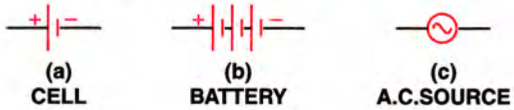


Fig. 9.3 Symbolic representation of source of current

When a strong current is needed, either we join a number of cells together in series (cathode of one cell connected to the anode of another cell), to form a *battery* or we use a storage cell. Fig. 9.3(b) represents the symbol for a battery (using three cells).

An *alternating current* (a.c.) source (mains) is represented by a sine curve (~) within a circle as shown in Fig. 9.3 (c).

(2) Key : It is used to put the current *on* and *off* in a circuit. It may be either a *plug key*,

* An alternating current (abbreviated as a.c.) is the current in an element (say, bulb) for which both the magnitude and direction change with time. The current repeats its value after a fixed time. The number of times current repeats its value in one second, is called the frequency of alternating current. The frequency of a.c. obtained from our mains is 50 Hz.

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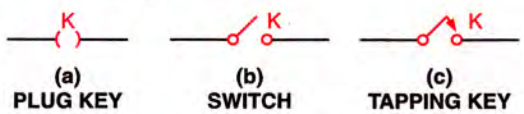
a *switch* or a *tapping key*. Fig. 9.4 shows the symbolic representation of these keys when they are open and when they are closed. A key is usually represented by the symbol *K*.

In laboratory, generally we use a plug key shown in Fig. 9.2(d). When key is open (*i.e.*, the plug is taken out), the circuit is incomplete and is called an *open circuit*. When key is closed (*i.e.*, the plug is put in), current flows through the circuit and is said to be *closed*. A tapping key is used when current is momentarily needed in the circuit.

When key is open



When key is closed

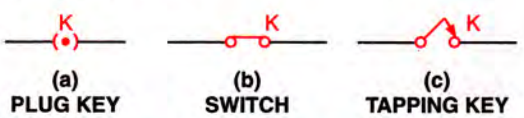


Fig. 9.4 Symbolic representation of different keys

(3) Resistance wire, resistance box, rheostat or variable resistance : A *resistance wire* is generally made from an alloy, called *manganin** and it has a fixed resistance depending upon its length and thickness. It is used as a standard resistance.

A *rheostat* [Fig. 9.2(e)] is a device by which resistance in a circuit can be varied continuously. It is used to adjust the magnitude of current in a circuit by changing the length of resistance wire included in the circuit. As shown in Fig. 9.5, it consists of an enamelled constantan wire wound in form of a coil (single layer) over an asbestos pipe fitted in an iron frame and provided with a sliding

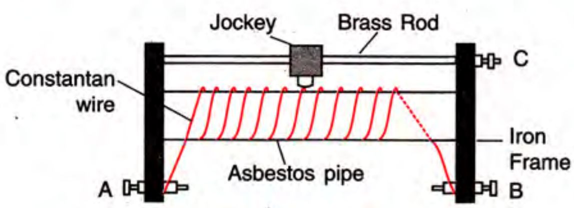


Fig 9.5 Rheostat

* Manganin is an alloy which is used for preparing wires in a resistance box and rheostat. It is composed of 84% copper, 12% manganese and 4% nickel.

contact (jockey) on a brass rod. It has three terminals *A*, *B* and *C*, out of which two terminals *A* and *B* are at the ends of resistance wire and the third terminal *C* is at the end of brass rod connecting the jockey. The enamel of the coiled wire is removed at the places where jockey touches the wire.

The wire between the two terminals *A* and *B* provides a fixed resistance equal to the resistance of entire length of wire. When rheostat is used as a *fixed resistance R*, connections are made with the terminals *A* and *B* as shown in Fig. 9.6 (a). Symbol *R* is used for a fixed resistance.

The main use of a rheostat is as a *smoothly varying resistance*. For this, connections are made between the terminals *C* and either of the fixed terminal *A* or *B* at the end, as shown in Fig. 9.6 (b). The jockey connected to the middle terminal *C* can be slided and by making its contact at different points, a *variable resistance* can be obtained. The current then enters at the positive terminal *A* (or *B*), it flows in the resistance wire of length up to the jockey and then leaves at the terminal *C*. Thus rheostat provides a continuously varying resistance to adjust current of a desired value in the circuit. Symbol *Rh* is used for a variable resistance.

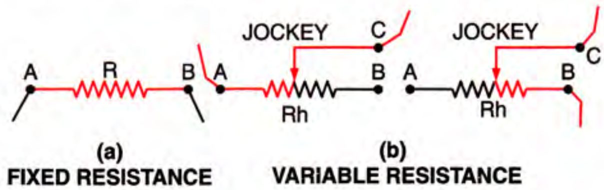


Fig 9.6 Symbolic representation of a rheostat

A *resistance box* [Fig. 9.2(f)] is provided with several standard resistances (say 1, 2, 2, 5, 10, 20, 20, 50, ... ohm) connected in series between the two terminals. A resistance of any desired value between 1 ohm to its maximum value (*i.e.*, sum of all resistances) can be used in step of one ohm by taking out the plug of that particular resistance from the resistance box.

(4) Ammeter : An ammeter [Fig. 9.2(g)] is an instrument used to measure the magnitude of current flowing in a circuit. It is joined in series in a circuit so that the entire current of the circuit passes through it. It is symbolically represented by the letter *A* enclosed in a circle as shown in Fig. 9.7. The + sign marked at one terminal of

it indicates that current must enter it through this terminal. Therefore this terminal is connected to the higher potential terminal of the current source. An ammeter must have a very low resistance so that the resistance of the circuit (or the current to be measured) may not alter when it is joined in the circuit. It has a dial on which deflection of needle shows the magnitude of current flowing in that circuit.

Fig. 9.7 Symbolic representation of an ammeter

Different kinds of ammeter are required to measure the alternating current and the direct current*.

(5) Voltmeter : A voltmeter shown in Fig. 9.2(h) is used to measure the potential difference between two points of a circuit. It is connected across the two points between which potential is to be measured (*i.e.*, in parallel to the flow of current). It is symbolically represented by the letter *V* enclosed in a circle as shown in Fig. 9.8. The + sign marked at one terminal of it indicates that current must enter it through this terminal. Therefore this terminal is connected to the point at higher potential. A voltmeter usually has a very high resistance so that it does not draw an appreciable current from the circuit. It has a dial on which deflection of needle shows the potential difference across the points of circuit in between which voltmeter is connected.

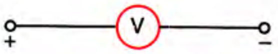


Fig. 9.8 Symbolic representation of a voltmeter

Different kinds of voltmeter are required to measure the alternating and the direct potential difference*.

(6) Galvanometer : A galvanometer [Fig. 9.2(i)] is used when we want to detect the presence of very weak current in an electric circuit or to know only the direction of flow of current in a circuit. It does not measure the magnitude of current in a circuit. It is joined in a circuit in series just like an ammeter. It is symbolically represented by the letter *G* enclosed in a circle as shown in Fig. 9.9. Current can enter or leave through any of its terminal, therefore no +/– signs are marked at its terminals. It has a dial with zero mark at its centre. The deflection of needle on it shows the presence of current and the direction of deflection indicates the direction of flow of current.

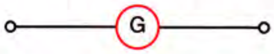


Fig. 9.9 Symbolic representation of a galvanometer

(7) Load : An appliance which is connected in a circuit is called a *load*. It may be just a resistance (*e.g.*, bulb, heater etc.) or a combination of different electrical components. It can be represented by the symbol *L* as shown in Fig. 9.10.

Fig. 9.10 Symbolic representation of a load

(8) Connecting wires : These are the wires used to connect various electrical components. They are made of highly conducting metal such as copper (or aluminium because of its low cost) so that they are of negligible resistance and do not change the resistance of the circuit. A connecting wire may be a thick wire or several fine wires twisted together. Generally, we use thick insulated copper wire as a connecting wire which is represented in a circuit diagram simply by a line.

9.4 SIMPLE ELECTRIC CIRCUIT

In our daily life, we use a torch in which a cell (or a combination of two or more cells) is connected to a bulb. This is the simplest electric circuit which uses only three components viz cell, bulb and switch. Fig. 9.11 shows a line diagram representing the simple electric circuit containing

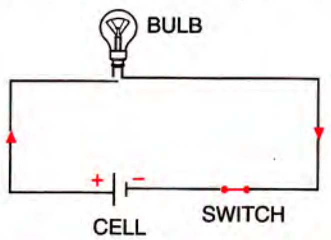


Fig. 9.11 An electric circuit of a cell, bulb and switch

* An ammeter or voltmeter used to measure alternating current is based on heating effect of current so it has graduations of unequal spacing while to measure direct current is based on magnetic effect of current so it has graduations of equal spacing.

a cell, a bulb and a switch. As the switch is closed, a current flows through the bulb and the bulb glows. The flow of current stops as the switch is opened. The bulb then ceases to glow.

Fig. 9.12 illustrates another simple electric circuit in which various components are the cell, key, rheostat, bulb, voltmeter and ammeter. Here the bulb acts as a load. It is clear that the ammeter, cell, key and rheostat are in series* with the bulb, while voltmeter is connected in parallel across** the bulb.

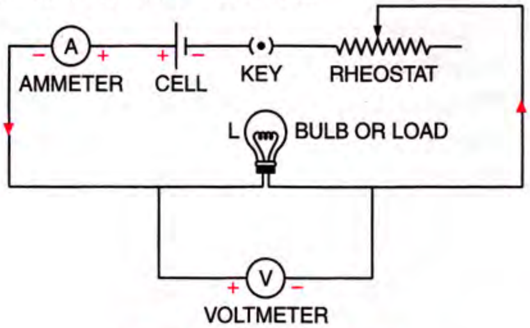


Fig. 9.12 Electrical circuit

To demonstrate the functions of various components of circuit shown in Fig. 9.12.

(i) First take out the plug from the key. This makes the circuit incomplete (or opens the circuit). The bulb does not glow and both the ammeter and the voltmeter read zero since no current flows in the circuit.

(ii) Now insert the plug in the key. The circuit is completed (or closed). The bulb glows and the ammeter reads current in the circuit, while the voltmeter reads potential difference (or voltage) across the bulb.

(iii) Then vary the resistance of the circuit by sliding the variable terminal (or jockey) of the rheostat. The glow of bulb changes as well as the readings of ammeter and voltmeter change. On decreasing the resistance by sliding the jockey to the left, the glow of bulb increases, the readings of ammeter and voltmeter also increase. On increasing the resistance by sliding the jockey to the right, the glow of bulb decreases, the readings of ammeter and voltmeter also decrease.

* The electrical components which are joined one after another and through which the same amount of current flows, are said to be in series.

** The electrical components which are joined with their one terminal forming one end and second terminal forming the other end, are said to be in parallel.

9.5 INSULATORS AND CONDUCTORS

Insulators : The substances which do not allow the current to flow through them, are called the *insulators*. They almost have no free electrons and they offer a very high resistance in the path of current. Some examples of insulators are cotton, rubber, plastic, wood, paper, glass, leather, pure water asbestors, chinaclay, *etc*.

Conductors : The substances which allow the current to flow through them easily, are called the *conductors*. All metals such as copper, aluminium, silver, iron, brass and steel are conductors. They have a large number of free electrons and they offer a very small resistance in the path of current. The human body also allows current to flow through it, so it is also a conductor. The impure water (or acidulated water) and mercury are also the conductors of electricity.

9.6 CLOSED AND OPEN CIRCUITS

The path along which current flows, is called a circuit. Current flows only if the circuit is *complete* (or *closed*). If the circuit is *open* (or *incomplete*), current does not flow.

For an electric circuit to be complete,each component of it must pass current through it i.e. it should be conducting. If there is an insulator in the path (or if the circuit is broken), the circuit is incomplete (or open) and the current will not flow through it.

In Fig. 9.13 (a), a bulb is connected between the two terminals *A* and *B* of a dry cell by two metal wires. The circuit is complete and the bulb glows. In Fig. 9.13 (b), the circuit from one terminal *A* of the cell to the bulb is broken, so the circuit is incomplete and the bulb does not glow. In Fig. 9.13 (c), one terminal *A* of the cell is connected to the bulb by a metal wire, while the other terminal *B* of cell is connected to the bulb by a thread (insulator), so the circuit is incomplete and the bulb does not glow.

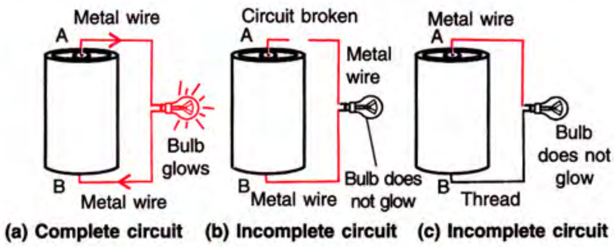


Fig. 9.13 Closed and open circuits

EXAMPLES

1. What is responsible for the flow of current through (i) a metallic conductor, (ii) an electrolyte ?

(i) In a metallic conductor, **free electrons** are responsible for the flow of current.

(ii) In an electrolyte, **both the positive and negative ions** are responsible for the flow of current.

2. A conductor carries a current of 0·2 A. (a) Find the amount of charge that will pass through the cross section of conductor in 30 s. (b) How many electrons will flow in this time interval if charge on one electron is $1{\cdot}6 \times 10^{-19}$ C ?

Given : $I = 0{\cdot}2$ A, $t = 30$ s

(a) Charge = Current × time

or $Q = I \times t = 0{\cdot}2 \times 30 = \mathbf{6\ C}$

(b) If n electrons flow and e is the charge on one electron, then total charge passed $Q = ne$

$$\therefore \quad n = \frac{Q}{e} = \frac{6}{1{\cdot}6 \times 10^{-19}} = \mathbf{3{\cdot}75 \times 10^{19}}$$

3. You are given a resistance wire *AB* connected with a cell and a key as shown in Fig. 9.14. You are required to measure the current in the wire *AB* and potential difference across it. Name the instruments that you would use and draw a labelled diagram to show how are they connected. Also mark the direction of current in each component.

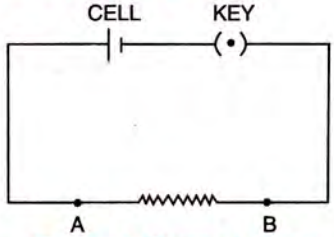


Fig. 9.14 Electrical circuit

To measure current, an ***ammeter*** is used and to measure the potential difference, a ***voltmeter*** is used. The ammeter (A) is connected in series with the resistance wire AB and cell, while the voltmeter (V) is connected in parallel across the wire AB. Care is taken that + marked terminal of ammeter (A) and voltmeter (V) is joined to the side of + ve terminal of cell. The completed diagram is given below in Fig. 9.15. The arrow marked in the diagram shows the direction of current.

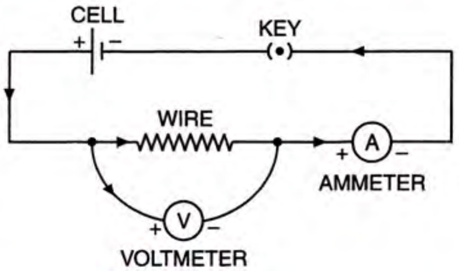


Fig. 9.15

EXERCISE 9 (A)

1. Name *one* d.c. source and *one* a.c. source.
   Ans. d.c. source : cell, a.c. **source :** mains.
2. Distinguish between d.c. and a.c.
3. What is an electric cell ?
4. What transformation of energy takes place when current is drawn from a cell ?
   Ans. Chemical energy changes to electrical energy.
5. Name the constituents of a cell.
   Ans. Two electrodes and an electrolyte in a vessel.
6. State the *two* kinds of cell. Give *one* example of each.
7. What is a primary cell ? Name *two* such cells.
8. What is a secondary cell ? Name *one* such cell.
9. State *three* differences between the *primary* and *secondary* cells.
10. What do you understand by the term current ? State and define its S.I. unit.
11. How much is the charge on an electron ?
    Ans. $-1{\cdot}6 \times 10^{-19}$ coulomb.
12. n electrons flow through a cross section of a conductor in time t. If charge on an electron is e, write an expression for the current in the conductor. **Ans.** $\frac{ne}{t}$
13. Name the instrument used to control the current in an electric circuit. **Ans.** Rheostat
14. In the electric circuit shown in Fig. 9.16, label the parts A, B, C, D, E, and F. State the function of each part. Show in the diagram the direction of flow of current.

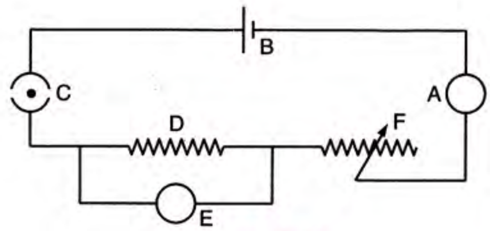


Fig. 9.16

15. What is the function of a key (or switch) in an electric circuit ?

Ans. To put on or off current in a circuit.

16. Write symbols and state functions of each of following components in an electric circuit : (i) key, (ii) cell, (iii) rheostat, (iv) ammeter, and (v) voltmeter.

17. (a) Complete the circuit given in Fig. 9.17 by inserting between the terminals *A* and *C*, an ammeter. (b) In the diagram mark the polarity at the terminals of ammeter and indicate clearly the direction of flow of current in the circuit, when the circuit is complete. (c) Name and state the purpose of Rh in the circuit.

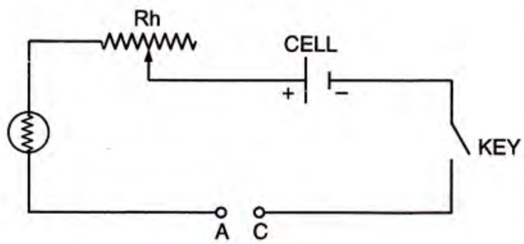


Fig. 9.17

18. What are conductors and insulators of electricity ? Give *two* examples of each.

19. Select conductors of electricity from the following : Copper wire, silk thread, pure water, acidulated water, human body, glass.

Ans. Copper wire, acidulated water and human body.

20. State *two* differences between a conductor and an insulator of electricity.

21. Distinguish between a closed circuit and an open circuit, with the use of suitable labelled diagrams.

22. Write the condition required for a circuit to be a closed circuit.

Multiple choice type :

1. A cell is used to :
   (a) measure current in a circuit
   (b) provide current in a circuit
   (c) limit current in a circuit
   (d) prevent current in a circuit.

   Ans. (b) provide current in a circuit

2. The unit of current is :
   (a) ampere (b) volt
   (c) ohm (d) coulomb. **Ans.** (a) ampere

3. The insulator of electricity is :
   (a) copper (b) silk
   (c) human body (d) acidulated water.

   Ans. (b) silk

Numericals :

1. A charge 0·5 C passes through a cross section of a conductor in 5 s. Find the current. **Ans.** 0·1 A

2. A current of 1·5 A flows through a conductor for 2·0 s. What amount of charge passes through the conductor ? **Ans.** 3 C

3. When starter motor of a car is switched on for 0·8 s, a charge 24 C passes through the coil of the motor. Calculate the current in the coil.

   Ans. 30 A

(B) POTENTIAL DIFFERENCE & RESISTANCE

9.7 FLOW OF ELECTRONS BETWEEN THE CONDUCTORS

When two charged conductors are joined by a metallic wire (or they are placed in contact), free electrons flow from a conductor having higher concentration of electrons to the conductor having lower concentration of electrons. The movement of electrons stops when concentration of electrons in both becomes equal. This can be understood by the following examples.

Examples : (1) In Fig. 9.18, a positively charged conductor *A* is joined by a metal wire to

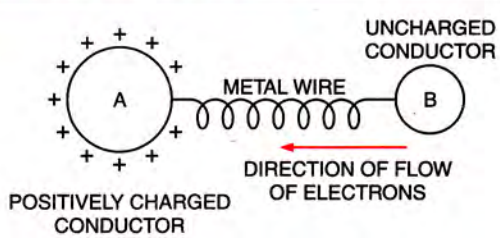


Fig. 9.18 Direction of flow of electrons from an uncharged conductor to a positively charged conductor

an uncharged conductor *B*. Electrons move from the uncharged conductor *B* to the charged conductor *A* to balance the deficit of electrons in

the conductor *A*. This movement of electrons continues till both the conductors have *equal concentration* of electrons.

(2) In Fig. 9.19, a negatively charged conductor *A* is joined by a metal wire to an uncharged conductor *B*. Electrons flow from the charged conductor *A* (which has excess of electrons) to the uncharged conductor *B* (which is neutral). This movement of electrons stops when both the conductors acquire *equal concentration* of electrons.

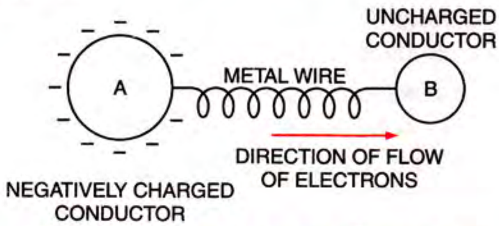


Fig. 9.19 Direction of flow of electrons from a negatively charged conductor to an uncharged conductor

(3) In Fig 9.20, two charged conductors *A* and *B* are joined by a metal wire. The conductor *A* is negatively charged, while the conductor *B* is positively charged. Electrons flow from the negatively charged conductor *A* (which has excess of electrons) to the positively charged conductor *B* (which has deficit of electrons). This flow of electrons continues till there is *equal concentration of* electrons in both the conductors.

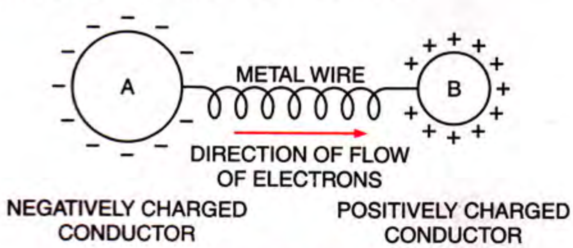


Fig. 9.20 Direction of flow of electrons from a negatively charged conductor to the positively charged conductor

Inference : From above examples, it is clear that the flow of electrons between two conductors joined by a metal wire can be maintained for a long time, if it is somehow made possible to maintain an excess of electrons in one conductor and a deficit of electrons in the other conductor. This is done in an *electric cell.*

In an electric cell, an excess of electrons on one electrode (*i.e.*, cathode) and a deficit of electrons on the other electrode (*i.e.*, anode) are maintained for a sufficiently long time by a chemical reaction within the cell. Thus, *an electric cell works as a source of electrons* and there is a continuous flow of electrons in the external circuit connected with the cell, in direction from cathode to anode.

9.8 DIRECTION OF THE ELECTRIC CURRENT — CONVENTIONAL AND ELECTRONIC FLOW

It is our common experience that if a body is released from a height, the body always moves from a higher level *A* (away from the earth) to the lower level *B* (nearer the earth surface) *i.e.*, from a higher gravitational potential to the lower gravitational potential (Fig. 9.21).

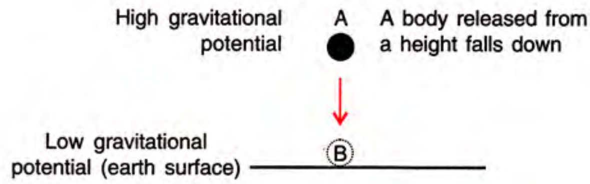


Fig. 9.21 A freely falling body

Similarly, if two vessels containing water up to different levels are joined together, water flows from the vessel *A* containing water up to a higher level to the vessel *B* containing water up to a lower level. This flow of water is due to the difference in hydrostatic pressure (or level of water) in the two vessels and it continues till the level of water is same in both the vessels (Fig. 9.22).

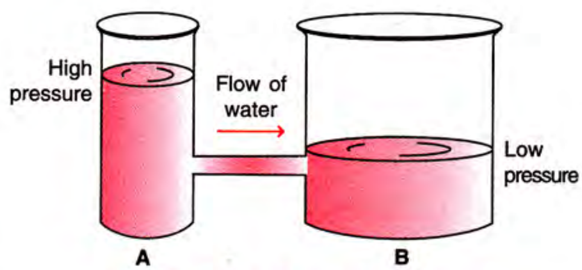


Fig. 9.22 Flow of water in two vessels

We have also read that if two bodies at different temperatures are kept in contact, heat flows by conduction from the body *A* at a higher temperature to the body *B* at a lower temperature till both the bodies acquire the same temperature (Fig. 9.23).

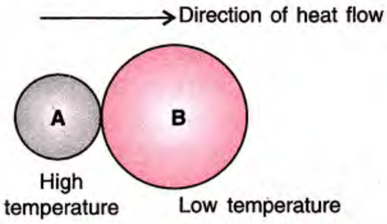


Fig. 9.23 Flow of heat in two bodies

In a similar manner, when two charged conductors are joined by a metal wire, the direction of flow of electrons is determined by a quantity called the *electric potential* of the conductor.

A conductor having an excess of electrons is said to be at a negative (or lower) potential, while having a deficit of electrons is said to be at a positive (or higher) potential.

In Fig. 9.24, a positively charged conductor A having a deficit of electrons (*i.e.*, at a high potential) is joined by a metal wire to a negatively charged conductor B having an excess of electrons (*i.e.*, at a low potential). The direction of flow of electrons is from the conductor B to the conductor A *i.e.*, from *low potential to high potential*. In keeping with the convention of flow from a higher to a lower level*, *the electric current is said to flow from a body at higher potential to a body at lower potential i.e., in a direction opposite to the direction of flow of electrons*. Thus, *the direction of flow of conventional current is opposite to the direction of flow of electrons*.

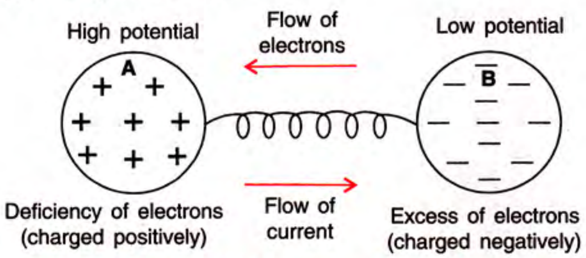


Fig. 9.24 Flow of electrons and flow of current between the two conductors

9.9 ELEMENTARY IDEA ABOUT WORK DONE IN TRANSFERRING CHARGE THROUGH A CONDUCTING WIRE; POTENTIAL DIFFERENCE ($V = W/Q$)

We know that the like charges repel and unlike charges attract, therefore to create an excess or deficit of electrons at a point, some work is to be done in moving the charges (or electrons) against the forces between them. The force between the two charges is zero when they are at infinite separation. Hence quantitatively, potential at a point is measured in terms of work done in bringing a charge q from infinity to that point. If work W' is done in bringing a charge q from infinity to a point, then potential at that point is

$$V = \frac{W'}{q} \qquad ....(9.4)$$

Potential is a **scalar** quantity. Its S.I. unit is joule/coulomb or volt (symbol V).

Similarly the potential difference between two conductors is measured in terms of the work done in transferring the charge from one conductor to the other, through a metallic wire.

The potential difference between two conductors is equal to the work done in transferring a unit positive charge from one conductor to the other conductor.

If work W is done in transferring a test charge q from one conductor to the other, the potential difference between them is

$$\boxed{V_1 - V_2 = \frac{W}{q}} \qquad ...(9.5)$$

*Potential difference is a **scalar** quantity.*

Unit of potential difference

From relation $V = \dfrac{W}{q}$

Unit of potential difference $= \dfrac{\text{Unit of work}}{\text{Unit of charge}}$.

The S.I. unit of work is joule and that of charge is coulomb (C), so the potential difference is measured in joule per coulomb which is named as volt (abbreviated as V). Thus

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}} \text{ or } 1 \text{ V} = \frac{1 \text{ J}}{1 \text{ C}}$$

Potential difference between two points is said to be 1 volt if work done in transferring 1 coulomb of charge from one point to the other point is 1 joule.

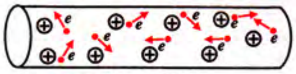
9.10 ELECTRICAL RESISTANCE

When current flows through a metallic wire it offers some obstruction called *resistance* to the flow of current through it. Thus we define resistance as below.

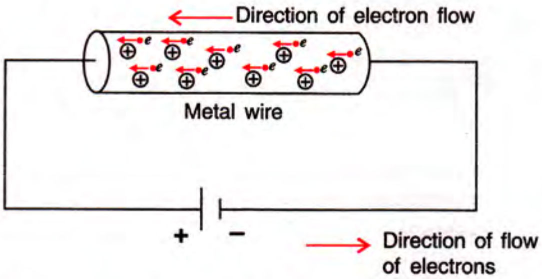
* Heat flows from a body at a high temperature to a body at a low temperature. Liquid flows from a high level to a low level, so we say that current flows from higher potential to lower potential.

The obstruction offered to the flow of current by the wire is called its electrical resistance.

Cause of resistance : A metal wire has free electrons which move in a random manner in absence of any cell connected across it [Fig. 9.25 (a)]. When the ends of the wire are connected to a cell, the electrons start moving from the negative terminal of cell to its positive terminal through the metal wire. During their movement, they collide with the fixed positive ions and other free electrons of the wire due to which their speed decreases and their direction of motion changes. After each collision, they again accelerate towards the positive terminal and suffer collisions with the other positive ions and free electrons again. This process continues. As a result, the electrons do not move in bulk with an increasing speed, but they drift towards the positive terminal. Thus the wire offers some resistance to the flow of electrons (or current) through it. Fig. 9.25 (b) shows the drift of electrons in a wire. The electrons are shown by dots(•) and the positive ions are shown as ⊕.



(a) Random motion of electrons in absence of potential difference across its ends



(b) Collisions of electrons with the positive ions due to which the wire offers resistance

Fig. 9.25 Drift of free electrons

Ohm's law : According to Ohm's law*, if a current I flows through a wire when potential difference across the ends of the wire is V, the resistance offered by the wire to the flow of current is the ratio of potential difference across it to the current flowing in it. *i.e.*,

Resistance of wire (R)

$$= \frac{\text{Potential difference across the wire } (V)}{\text{Current flowing in the wire } (I)}$$

$$R = \frac{V}{I} \quad \text{or} \quad V = IR \qquad \dots (9.6)$$

Resistance is a **scalar** quantity

Unit of resistance : From relation $R = \frac{V}{I}$,

$$\text{Unit of resistance} = \frac{\text{Unit of potential difference}}{\text{Unit of current}}.$$

The S.I. unit of potential difference is volt (V) and that of current is ampere (A), hence S.I. unit of resistance is volt per ampere which is named as ohm (symbol Ω). Thus,

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}} \text{ or } 1\ \Omega = \frac{1\text{ V}}{1\text{ A}}$$

The resistance of a conductor is said to be 1 ohm if a current of 1 ampere flows through it when the potential difference across its end is 1 volt.

Factors affecting the resistance of a conductor

(1) The material of wire : The resistance of a wire depends on the number of collisions which the electrons moving through it suffer with the other electrons and fixed positive ions of the wire. In different materials, the concentration of electrons and the arrangement of atoms are different, therefore, *the resistance of wires of same length, same area of cross section, but of different materials differ depending on their material.* Good conductors having higher concentration of free electrons (such as metals) offer less resistance.

(2) The length of wire : The number of collisions suffered by the moving electrons will be more if they have to travel a longer distance in wire, therefore, a *long wire offers more resistance than a short wire* (*i.e.*, resistance of a wire ∝ length of wire).

(3) The area of cross section of wire : In a thick wire, electrons get a larger area of cross section to flow as compared to a thin wire, therefore, *a thick wire offers a less resistance* (*i.e.*, resistance of wire ∝ 1/area of cross section of wire).

* Ohm's law states that current flowing through a conductor is directly proportional to the potential difference applied across its ends provided its temperature is constant. *i.e.*, $I \propto V$ or $V \propto I$ or $V = IR$ where R is the resistance of conductor.

(4) The temperature of the wire : If the temperature of wire increases, ions in it vibrate more violently. As a result, the number of collisions increases and hence the resistance of wire increases (*i.e., the resistance of a wire increases with the increase in its temperature).*

EXAMPLES

1. A conductor *AB* is joined to a cell with its end *A* at a low potential and the end *B* at a high potential. (a) State the direction of flow of electrons in it. (b) What will be the direction of flow of conventional current in the conductor ?

(a) The flow of electrons is from ***A* to *B*** (*i.e.,* from a low potential to a high potential).

(b) The conventional current in conductor will flow from ***B* to *A*** (*i.e.*, from a high potential to a low potential).

2. Two conductors *A* and *B* are joined by a copper wire. State the direction of flow of electrons in each of the following cases :

(i) If *A* is positively charged and *B* is uncharged.

(ii) If *A* is negatively charged and *B* is uncharged.

(iii) If *A* is positively charged and *B* is negatively charged.

Ans. (i) *B* to *A* (ii) *A* to *B* (iii) *B* to *A*.

3. What amount of work is needed in moving 2 C charge through a potential difference of 8 V ?

Given : $q = 2$ coulomb, $V = 8$ volt

$\therefore$ Work needed $W = qV = 2 \times 8 = \mathbf{16\ J.}$

4. A cell is connected to a bulb which develops a potential difference of 12 volt across it. The current in circuit is measured to be 2 ampere. Find the resistance offered by the filament of bulb to the flow of current.

Given : $V = 12$ volt, $I = 2$ ampere.

Resistance of filament of bulb

$$R = \frac{V}{I} = \frac{12\text{ volt}}{2\text{ ampere}} = \mathbf{6\ ohm.}$$

5. Calcualte the potential difference across the ends of a wire of resistance 2 Ω when a current 1·5 A passes throug it.

Given : $R = 2\ \Omega$, $I = 1{\cdot}5$ A

From Ohm's law, $V = IR$

Potential differences $V = 1{\cdot}5 \times 2 = \mathbf{3{\cdot}0\ V}$

6. Calculate the current flowing through a wire of resistance 7·5 Ω connected to a battery of potential difference 1·5 V.

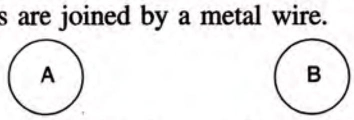
Given : $R = 7{\cdot}5\ \Omega$, $V = 1{\cdot}5$ V

From Ohm's law, $V = IR$

Current in wire $I = \frac{V}{R} = \frac{1{\cdot}5}{7{\cdot}5} = \mathbf{0{\cdot}2\ V}$

EXERCISE 9 (B)

1. Fig. 9.26 below shows two conductors *A* and *B*. Their charges and potentials are given in diagram. State the direction of (i) flow of electrons, and (ii) flow of current, when both the conductors are joined by a metal wire.



Q = – 10 coulomb
V = 5 volt

Q = 5 coulomb
V = 10 volt

Fig. 9.26

Ans. (i) *A* to *B*, (ii) *B* to *A*

2. How is the direction of flow of current between the two charged conductors determined by their potentials ? **Ans.** Current flows from high potential to low potential.

3. Explain the concept of electric potential difference in terms of the work done in transferring the charge.

4. Define the term potential difference ?

5. State and define the S.I. unit of potential difference.

6. 'The potential difference between two conductors is 1 volt'. Explain the meaning of this statement.

7. What do you understand by the term resistance ?

8. Explain why does a metal wire when connected to a cell offer resistance to the flow of current.

9. State and define the S.I. unit of resistance.

10. State Ohm's law.

11. How are the potential difference (V), current (I) and resistance (R) related ? **Ans.** $V = I R$
12. 'The resistance of a wire is 1 ohm'. Explain the meaning of this statement.
13. How is the current flowing in a conductor changed if the resistance of conductor is doubled keeping the potential difference across it the same ? **Ans.** Halved.
14. State *three* factors on which the resistance of a wire depends. Explain how does the resistance depend on the factors stated by you.
15. How is the resistance of a wire affected if its (a) length is doubled, (b) radius is doubled ?
Ans. (a) becomes more or twice
(b) becomes less or one-fourth.
16. State whether the resistance of filament of a bulb will decrease, remain unchanged or increase when it glows. **Ans.** Increase
17. Name the physical quantities of which the units are : (i) volt, (ii) coulomb, (iii) ohm, (iv) ampere.
Ans. (i) Potential difference (ii) charge (iii) resistance, (iv) current.

Multiple choice type :

1. Current in a circuit flows :
(a) in direction from high potential to low potential
(b) in direction from low potential to high potential
(c) in direction of flow of electrons
(d) in any direction.
Ans. (a) in direction from high potential to low potential
2. The unit of potential difference is :
(a) ampere (b) volt
(c) ohm (d) coulomb.
Ans. (b) volt
3. On increasing the resistance in a circuit, the current in it :
(a) decreases (b) increases
(c) remains unchanged (d) nothing can be said.
Ans. (a) decreases

Numericals :

1. In transferring 1·5 C charge through a wire, 9 J of work is needed. Find the potential difference across the wire. **Ans.** 6 V
2. A cell of potential difference 12 V is connected to a bulb. The resistance of filament of bulb when it glows, is 24 Ω. Find the current drawn from the cell. **Ans.** 0·5 A
3. A bulb draws current 1·5 A at 6·0 V. Find the resistance of filament of bulb while glowing. **Ans.** 4·0 Ω
4. A current 0·2 A flows in a wire of resistance 15 Ω. Find the potential difference across the ends of the wire. **Ans.** 3·0 V

(C) EFFICIENT USE OF ENERGY

9.11 EFFICIENT USE OF ENERGY

The meaning of the efficient use of energy is to reduce the cost and amount of energy to be used to provide us the various products and services. Energy efficiency can be achieved by adopting more efficient ecofriendly technologies and processes. This results in reduction of (i) the cost of energy and (ii) the emission of green house gases.

Examples : (1) By properly insulating a home, it is possible to maintain a comfortable temperature inside. It will reduce the cost of heating devices in winter and cooling devices in summer.

(2) The use of the fluoroscent lights or natural skylight instead of the traditional incandescent light bulbs, reduces the amount of energy required to attain the same level of illumination.

(3) The use of compact fluoroscent lights (CFL) saves 67% energy and they may last 6 to 10 times longer than the incandescent lights.

(4) The use of LED (light emitting diode) bulbs for lighting reduces the consumption of energy drastically. It is also helpful in reducing the global warming and the harmful effect of mercury used in the fluorescent light.

(5) The modern energy efficient appliances such as refrigerators, freezers, ovens, stoves, dishwashers, dryers, etc. make use of significantly less energy than the older appliances. Nowadays appliances are star rated according of their efficient use of electricity.

(6) A building's location and its surroundings play a key role in regulating its temperature and illumination. Proper placement of the windows and skylights and the use of

architectural features that reflect light into the building can reduce the need of the artificial lighting. White roof systems can save more energy in summers.

(7) The use of advanced boilers and furnaces in industry can save sufficient amount of energy in attaining the high temperature by burning less fuel. Use of such technologies is more efficient and less polluting.

(8) The fuel efficiency in the vehicles can be increased by reducing the weight of the vehicle, using the advanced tyres and the computer controlled engines.

According to the International Energy Agency (IEA), the improved energy efficiency in buildings, industries and transportation could reduce the world's energy need in 2050 by one-third and thus it can help in control of global emission of the green house gases.

9.12 SOCIAL INITIATIVES

The rapid depletion of energy resources and the adverse environmental impacts of energy use, has led to (i) the efforts so as to develope the energy efficient machines (ii) the technologies which can reduce the energy expenditure and minimize the environmental hazards. It has become essential to create awareness amongst the people and build in them the trends of sensitive use of the resources and products so as to reduce the use of electricity. Public awareness can be improved through mass-media and children's participation in compaigns and eco-club activities. Community involvement will surely be effective in reducing the misuse of electricity. The non-government organisations (NGO's) can be used to create social awareness of the sensitive use of the resources.

EXERCISE 9 (C)

1. What is meant by the efficient use of energy ?
2. State *two* ways to save the energy.
3. How does the proper insulation of home save energy ?
4. Which of the following device is most efficient for the lighting purpose :

   LED, CFL, Fluorescent tube light, Electric bulb.
5. Give an example to explain that the use of modern eco-friendly technologies is more efficient and less polluting.
6. Describe *three* ways for the efficient use of energy.
7. What social initiatives must be taken for the sensitive use of energy ?

Multiple choice type :

1. The most non-polluting and efficient lighting device is :

   (a) CFL (b) LED

   (c) Fluorescent light (d) Electric bulb.

   Ans. (b) LED

2. IEA is the short form of :

   (a) Indian Energy Association

   (b) Indian Eco Academy

   (c) International Energy Agency

   (d) International Eco Academy..

   Ans. (c) International Energy Agency

10 MAGNETISM

Syllabus :

(i) Induced magnetism; Magnetic field of earth, neutral points in magnetic fields.

Scope – Magnetism : magnetism induced by bar magnets on magnetic materials; induction precedes attraction, lines of magnetic field and their properties, evidences of existence of earth's magnetic field, magnetic compass; uniform magnetic field of earth and non-uniform field of a bar magnet placed along magnetic north-south; neutral point; properties of magnetic field lines.

(ii) Introduction fo electromagnets and its uses.

(A) INDUCED MAGNETISM AND NEUTRAL POINTS

10.1 INTRODUCTION

The first known magnets were the pieces of *lodestone*, an ore of iron oxide (Fe_3O_4) found in large quantities in Magnesia, in Asia Minor. *This ore was found to possess two properties : (i) it attracts small pieces of iron, and (ii) it sets itself along a definite direction when it is suspended freely.* The Chinese, earlier than 2500 B.C., used these pieces to guide their boats. The pieces of lodestone found in nature were later on called the *natural magnets*. The word magnet has been derived from magnesia.

The natural magnets are found in quite irregular and odd shapes. They are not magnetically strong enough for use. Therefore, for different uses, artificial magnets are prepared from iron in different convenient sizes and shapes such as *bar magnet, horse shoe magnet, magnetic needle, magnetic compass, etc.*

If a magnet is suspended with a silk thread such that it is free to rotate in a horizontal plane, it *sets itself always pointing in the geographic north-south direction* as shown in Fig. 10.1. Depending on the direction in which an end of the magnet rests, its polarity is named as *north* or *south*.

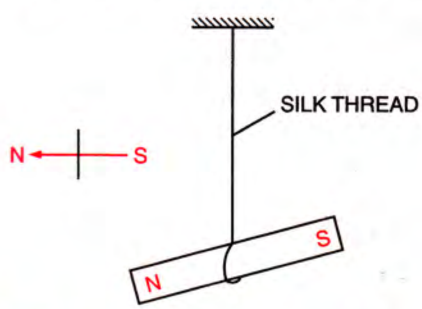
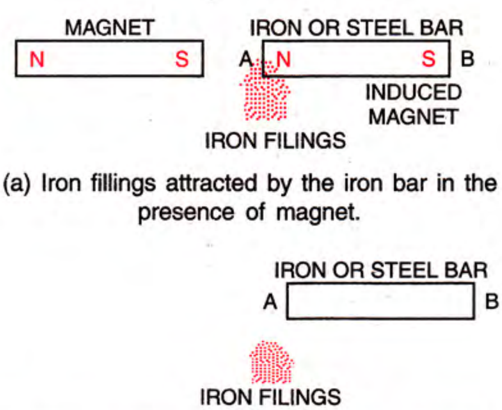


Fig. 10.1 Setting of a freely suspended magnet

Two like poles (both north poles or both south poles) repel each other, while two unlike poles (one north pole and the other south pole) attract each other.

10.2 INDUCED MAGNETISM (MAGNETISM INDUCED BY A BAR MAGNET ON THE MAGNETIC MATERIALS)

When an unmagnetised bar *AB* of a magnetic material such as soft iron or steel, is placed near or in contact with a magnet as shown in Fig 10.2 (a), the bar *AB* becomes a magnet *i.e.*, it acquires the property of attracting iron filings when they are brought near its ends. If the magnet is now removed, it is seen that nearly all the iron filings which have clung to it, fall down *i.e.*, the bar *AB* loses its magnetism [Fig. 10.2(b)]. Thus, the *bar of a magnetic material behaves like a magnet so*



(a) Iron fillings attracted by the iron bar in the presence of magnet.

(b) Iron fillings fall from the bar on removal of the magnet

Fig. 10.2 Induced magnetism

long it is kept near or in contact with a magnet. The magnetism so produced is called *induced magnetism*. Thus

The temporary magnetism acquired by a magnetic material when it is kept near (or in contact with) a magnet, is called induced magnetism.

The process in which a piece of magnetic material acquires the magnetic properties temporarily in presence of another magnet near it, is called the *magnetic induction.*

If polarity at the ends *A* and *B* of the bar *AB* is tested with a compass needle, it is found that the polarity developed at the end *A* is north (opposite to the polarity of the magnet near the end *A*) and the polarity at end *B* is south (*i.e.*, similar to the polarity at the end of the magnet near the end *A*). Thus,

A magnetic pole induces an opposite polarity on the near end and a similar polarity on the farther end of the iron bar.

Induction precedes attraction

Now we can explain how an ordinary piece of iron is attracted towards a magnet. When a piece of iron is brought near one end of a magnet (or one end of a magnet is brought near the piece of iron), the nearer end of the piece acquires an opposite polarity by magnetic induction. Since unlike poles attract each other, therefore iron piece is attracted towards the end of the magnet. Thus, piece of iron first becomes a magnet by induction and then it is attracted. In other words, *induction precedes attraction.*

Induced magnetism is temporary

If one pole of a bar magnet is brought near the small iron nails, they form a chain of nails as shown in Fig. 10.3. The reason is that the bar magnet by induction magnetises an iron nail which gets attracted by the magnet and clings to it. This

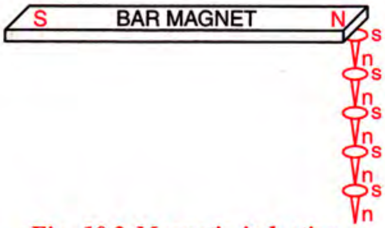


Fig. 10.3 Magnetic induction

magnetised nail magnetises the other nail near it by magnetic induction and attracts it. This process continues till force of attraction of magnet on first nail is sufficient to balance the total weight of all the nails in chain.

Now holding the uppermost nail in position by fingers, if magnet is removed, we find that all nails fall down. The reason is that on removing the magnet, the uppermost nail loses its magnetism, so all other nails also lose their magnetism, they get separated from each other and they all fall down due to force of gravity. This shows that *the magnetism acquired by induction is purely temporary.* It lasts so long as the magnet causing induction remains in its vicinity.

10.3 LINES OF MAGNETIC FIELD

If a magnetic compass is placed on a table, it is found that its needle rests in geographic north-south direction*. But when it is placed near a magnet, the needle swings and then rests in some other direction. As the compass is placed at different positions around a magnet, the direction in which the needle rests, changes such that its one end always points towards the nearer pole of the magnet. This behaviour of needle is due to the influence of the magnet near it. The region in which the compass gets influenced is called the *magnetic field* of the magnet.

The space around a magnet in which the needle of a compass rests in a direction other than the geographic north-south direction, is called magnetic field of the magnet.

As the distance of point from the magnet increases, the effect of its magnetic field dicreases.

Magnetic field is a ***vector*** *quantity*. The magnitude of magnetic field at a point is measured by the force which a magnetic pole placed at that point, experiences, while the direction of magnetic field is the direction in which the needle of compass rests when it is placed at that point.

If we place a magnet below a sheet of stiff paper (or a glass plate) and spread some iron filings uniformly over the glass plate, then on tapping the glass plate gently, the iron filings arrange themselves along the curved lines as

* Due to the earth's magnetic field.

shown in Fig. 10.4. The reason is that due to magnet, each piece of iron filing gets magnetised by magnetic induction and experiences a force due to the magnet and arrange itself along the curved line. These curved lines are called the *magnetic field lines.*

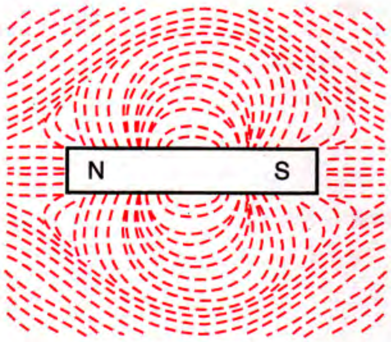


Fig. 10.4 Arrangement of iron filings over a magnet showing the magnetic field of the bar magnet

When a compass needle is placed at any point in a magnetic field, its needle rests along the magnetic field line. An arrow is marked on the magnetic field line from south pole of the needle to its north pole. The arrow indicates the direction of magnetic field at that point. Thus

A magnetic field line is a continuous curve in a magnetic field such that tangent at any point of it gives the direction of the magnetic field at that point.

10.4 PROPERTIES OF MAGNETIC FIELD LINES

The magnetic field lines have following properties :

(1) They are closed and continuous curves.

(2) Outside the magnet, they are directed from the *north* pole towards the *south* pole of the magnet*.

(3) The tangent at any point on a field line gives the direction of magnetic field at that point.

(4) They never intersect one another. If two field lines intersect, there would be two directions of the magnetic field at that point which is not possible. Fig 10.5 shows two magnetic field lines *PQ* and *PR* intersecting each other at a point *P*. It would mean that if a compass needle is placed at the point *P*, north pole of its needle will point in two directions *PQ* and *PR* simultaneously which is not possible.

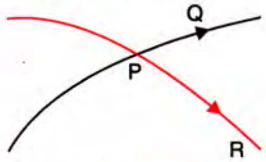


Fig. 10.5 A compass needle placed at the point P cannot show the two directions PQ and PR simultaneously

(5) They are crowded near the poles of the magnet where the magnetic field is strong and are far separated near the middle of the magnet and far from the magnet, where the magnetic field is weak.

(6) Parallel and equi-distant field lines represent a *uniform* magnetic field. The earth's magnetic field in a limited space is uniform.

(7) They behave like the stretched elastic rubber strings.

10.5 MAGNETIC FIELD OF EARTH (Evidences of existence of earth's magnetic field)

Our earth itself has a magnetic field and it behaves like a magnet. The existence of earth's magnetic field is based on the following facts :

(i) A freely suspended magnetic needle always rests in geographic north-south direction.

(ii) An iron rod buried inside the earth along north-south direction becomes a magnet.

(iii) Neutral points are obtained on plotting the field lines of a magnet where the net magnetic field in zero.

(iv) A magnetic needle rests with its geometric axis making different angles with horizontal when suspended at different places on the earth.

(i) A freely suspended magnetic needle always rests in geographic north-south direction — When a magnetic needle (or a magnet) is suspended such that it is free to rotate in a horizontal plane, it always rests indicating the geographic north-south direction. But the north pole of a magnet will point towards the geographic

* Inside the magnet, the magnetic field lines are directed from *south* pole towards the *north* pole and thus a closed and contineous curve is formed.

north only when there is a magnetic south pole attracting it. Similarly the south pole of the magnet will point towards the geographic south when there is a magnetic north pole attracting it. Therefore we can assume a magnet inside the earth which must have its south pole in the geographic north and north pole in the geographic south.

(ii) An iron rod buried inside the earth along north-south direction becomes a magnet — If an iron rod is buried few metres inside the earth keeping it along north-south direction, after some days it is found that the rod becomes a weak magnet. It is possible only if the earth itself behaves like a magnet.

(iii) Neutral points are obtained on plotting the field lines of a magnet — If a magnet is placed in a horizontal plane with its north pole facing towards the geographic north and the magnetic field lines are plotted, we obtain *two* neutral points, one on either side of the magnet, on its broad side-on position. Similarly, if the magnet is placed in a horizontal plane with its north pole facing towards the geographic south and the magnetic field lines are plotted, we obtain *two* neutral points, one on either side of the magnet on its end-on position. At each neutral point, the resultant magnetic field is zero *i.e.*, if a compass needle is placed at a neutral point, it rests in any direction. The reason for zero resultant magnetic field at the neutral point is that the magnetic field produced by the magnet is neutralised by some other equal and opposite magnetic field. This other magnetic field is actually the horizontal component of the earth's magnetic field.

(iv) A magnetic needle rests making different angles with horizontal when suspended at different places of the earth — If a magnetic needle is suspended such that it is free to rotate in a vertical plane and it is taken around the earth through its geographic poles, we find that at *two* places, magnetic needle becomes normal to the earth surface *i.e.*, it becomes vertical. These points are called the *earth's magnetic poles*. At *two* places it becomes parallel to the earth surface *i.e.*, it becomes horizontal. These points lie on *earth's magnetic equator*. At other places, it rests making different angles with the horizontal as shown in Fig. 10.6. It implies that the earth itself has a magnetic field.

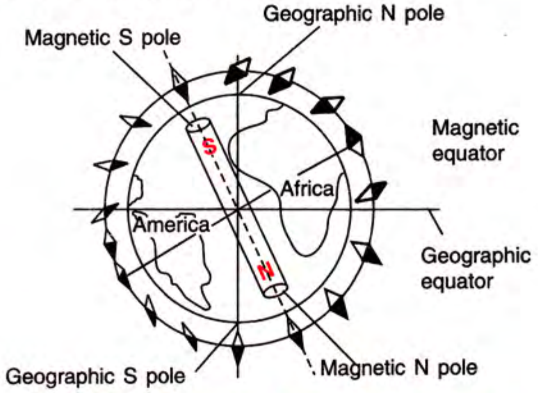


Fig. 10.6 The magnetic needle at different places on earth

> *Two places where the magnetic needle becomes vertical are called the magnetic poles.*
>
> *The line joining the places where the magnetic needle becomes horizontal, is called the magnetic equator.*

Conclusion : On the basis of above facts, it can be concluded that the earth behaves as if a huge bar magnet is present at its centre with its magnetic south pole in the geographic north and the magnetic north pole in the geographic south. Actually, the geographic poles do not coincide with the earth's magnetic poles, but they are somewhat displaced. The magnetic axis of the earth makes an angle of 17° with the axis of rotation of the earth. The magnetic south pole of earth is in Canada at a distance nearly 2240 km from the geographic north pole at 70·75° north latitude and 96° west longitude, while the earth's magnetic north pole is at a distance nearly 2240 km from the geographic south pole at 73° south latitude and 155° east longitude. It has been experimentally observed that the positions of these poles are not stationary, but they gradually change over a long period of time.

Magnetic Field Lines of Earth

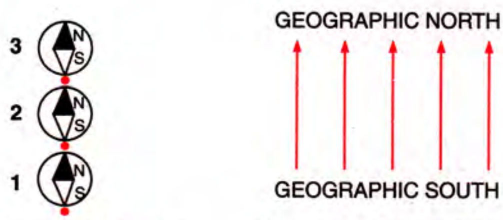
In a limited space, the magnetic field lines of earth are parallel and equidistant to each other as shown in Fig. 10.7(b). They are always directed from the geographic south to the geographic north. They are horizontal at the magnetic equator and vertical at the magnetic poles, but at any other point, they are inclined to the horizontal.

The magnetic field lines of the earth are normal to earth surface near the magnetic poles and parallel to earth surface near the magnetic equator.

10.6 PLOTTING OF UNIFORM MAGNETIC FIELD LINES OF EARTH

Earth's magnetic field is uniform in a limited space. Experimentally we can plot uniform magnetic field lines of earth as follows.

Experiment : Fix a sheet of paper on a drawing board (or a table top) by means of *brass pins*. Place a small compass needle at position 1 [Fig. 10.7 (a)] and looking from top of the needle, mark *two* pencil dots exactly in front of two ends of the needle. Then move the compass needle to position 2 in such a way that one end of the needle coincides with the second pencil dot. Mark the position of the other end of needle with a dot. Repeat the process of moving the compass needle to position 3, 4, ... to obtain several dots. On joining the different dots, you will get a straight line. Thus one magnetic field line of earth is traced.



(a) Plotting a field line with a compass needle

(b) Lines of uniform magnetic field of earth

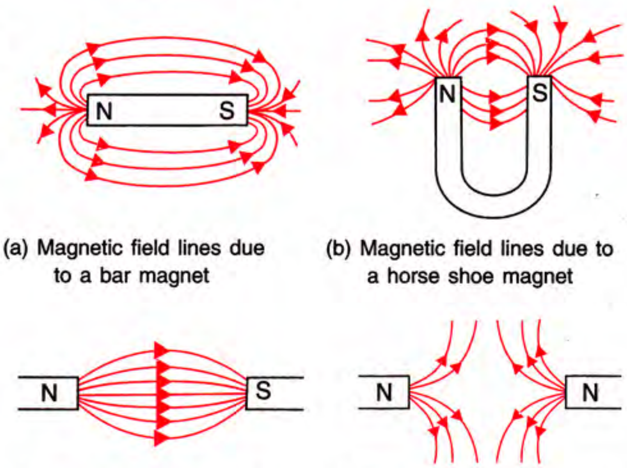
Fig. 10.7 Magnetic field lines of earth

Repeat the process starting from a different point and trace out another magnetic field line. In this manner, draw several magnetic field lines starting from the different points. Label each line with an arrow from the south pole of needle towards the north pole to indicate the direction of the magnetic field. Fig. 10.7 (b) shows several magnetic field lines so obtained.

It is noticed that these *lines do not intersect each other*. They are parallel and equidistant. They are directed from geographic south to geographic north (*i.e.*, the direction in which a magnetic needle, suspended freely in a horizontal plane, rests).

10.7 PLOTTING OF NON UNIFORM MAGNETIC FIELD OF A STRONG BAR MAGNET AND NEUTRAL POINTS

The magnetic field around a bar magnet (or a horse shoe magnet) is non-uniform. The magnetic field lines in a non-uniform magnetic field are not equispaced and parallel, but they are curved (either converging or diverging). The closely spaced magnetic field lines at a place represent a strong magnetic field at that place, while the widely spaced magnetic field lines at a place represent a weak magnetic field at that place. Fig. 10.8 shows the non-uniform magnetic field lines due to (a) a bar magnet, (b) a horse shoe magnet, (c) two unlike poles facing each other and (d) two like poles facing each other.



(a) Magnetic field lines due to a bar magnet

(b) Magnetic field lines due to a horse shoe magnet

(c) Magnetic field lines due to two unlike poles facing each other

(d) Magnetic field lines due to two like poles facing each other

Fig. 10.8 Non-uniform magnetic field lines

We shall now plot the non-uniform magnetic field lines of a bar magnet placed in the magnetic meridian (*i.e.*, along the direction in which a freely suspended magnet rests) in the following *two* positions :

(1) When the magnet is placed with its north pole pointing towards north.

(2) When the magnet is placed with its south pole pointing towards north.

(1) *When the magnet is placed with its north pole pointing towards north*

Fix a sheet of white paper on a drawing board with the help of *brass pins*. Mark north-south direction in the

middle of the paper by keeping a compass needle on it. Draw a line along this direction and place a bar magnet on the paper along this line with its *north pole pointing towards north*. Mark its outline with a fine pencil. Now place the compass needle close to the *north* pole of the magnet and looking from above, mark *two* pencil dots exactly in front of two ends of the needle. Then move the compass needle in such a way that one end of the needle coincides with the second pencil dot. Mark position of the other end of the needle with a dot. Repeat the process of moving the compass needle till other end of the bar magnet is reached. Join different dots to get a continuous smooth curve. Thus, one magnetic field line is traced.

Repeat the process from the same pole of the magnet, but starting from a different point and trace out another magnetic field line. In this manner, draw several magnetic field lines starting from the different points near the same pole of the magnet. Label each line with an arrow from the north pole towards the south pole of the magnet (or from south pole of compass needle to its north pole) to indicate the direction of magnetic field at that place.

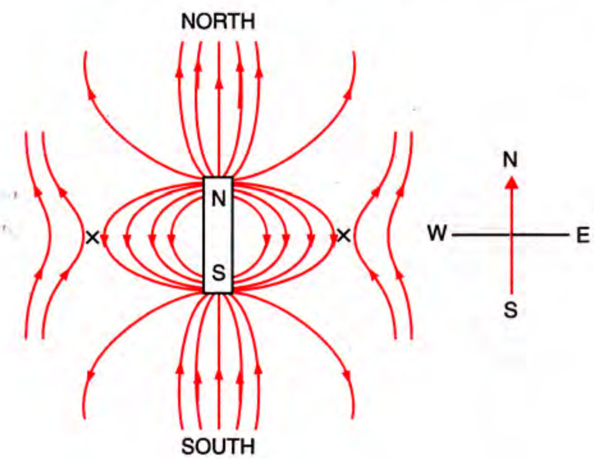


Fig. 10.9 Magnetic field lines of a bar magnet when its north pole N faces geographic north

The magnetic field lines obtained are shown in Fig. 10.9. These are due to the combined effect of (i) the magnetic field of magnet and (ii) the earth's magnetic field.

From Fig. 10.9, it is noted that

(i) The magnetic field lines are curved in the vicinity of magnet. They are mainly due to the magnetic field of magnet which is stronger than the magnetic field of the earth. As the distance from the magnet increases, the strength of the magnetic field due to the magnet decreases and at distant points, it becomes weaker than the earth's magnetic field. The magnetic field lines are therefore parallel to each other at distant points. Here they are mainly due to the earth's magnetic field.

(ii) There are *two* points equidistant from the centre of the magnet marked as × in Fig. 10.9 in *east and west directions* where the magnetic field of the magnet and the horizontal component of the earth's magnetic field are equal in magnitude and they are in opposite directions such that they neutralise each other. These are the *neutral points.* A compass needle when placed at these points, remains unaffected and the needle rests in any direction.

(2) *When the magnet is placed with its south pole pointing towards north*

In this case, the bar magnet is placed on the paper along the magnetic meridian with its *south pole pointing towards north* and lines of magnetic field are traced following the same method as described above. Fig. 10.10 shows the magnetic field lines due to the combined effect of (i) the magnetic field of the magnet and (ii) the earth's magnetic field.

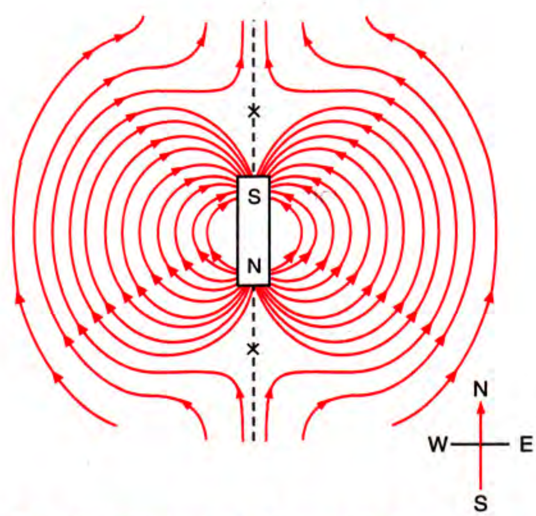


Fig. 10.10 Magnetic field lines of a bar magnet when its north pole N faces geographic south

From Fig. 10.10, we notice that

(i) The magnetic field lines are curved in the vicinity of the magnet and they are mainly due to the magnetic field of the magnet which is much stronger than the earth's magnetic field. As the distance from the magnet increases, the

strength of the magnetic field due to the magnet decreases and at distant points, it becomes weaker than the earth's magnetic field. The magnetic field lines *are nearly parallel straight lines from south to north,* at the distant points from the magnet. They are mainly due to the earth's magnetic field.

(ii) There are *two* points equidistant from the centre of the magnet marked as × in Fig. 10.10 *in the north and south directions* where the magnetic field of the magnet and the horizontal component of the earth's magnetic field are equal in magnitude and they are in opposite directions such that the two fields neutralise each other. At these points, the compass needle remains unaffected and the needle comes to rest pointing in any direction. These points are the *neutral points.*

10.8 NEUTRAL POINTS

Neutral points are the points where the magnetic field of magnet is equal in magnitude to the earth's horizontal magnetic field, but it is in opposite direction. Thus the resultant (or net) magnetic field at the neutral points is zero.

The neutral points are situated symmetrically on either side of a magnet at equal distances from the centre in east-west direction, if the north pole of the magnet faces towards geographic north. But the neutral points are on either side of the magnet at equal distances from the centre in north-south directions, if south pole of the magnet faces towards geographic north. If a compass needle is placed at the neutral points, it remains unaffected (*i.e.*, it comes to rest pointing in any direction) because the net magnetic field at these points is zero.

EXAMPLES

1. A horse shoe magnet has two iron needles attached at its ends. Show on a diagram the positions occupied by the needles and name the phenomenon which comes into play.

Fig. 10.11 shows the iron needles attached at the ends of a horse shoe magnet. The lower ends of both the needles get attracted towards each other, since they have opposite polarities. The upper ends touching the poles of the magnet, have polarities opposite to that of the magnet. This phenomenon is called **magnetic induction**.

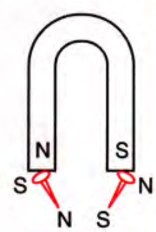


Fig. 10.11

2. You are given two identical bars, one of which is magnetised. How will you select the magnetised bar ?

The two bars are suspended by a silk thread one by one, so as to swing freely in a horizontal plane. The bar which rests in the north-south direction will be the magnetised bar.

3. You are given a magnetised bar and a compass needle. How will you mark polartiy at the ends of bar ?

The two ends of bar are brought near the north pole of the compass needle one by one. The end of bar which repels the north pole of the compass needle will be the *north pole,* while the end of the bar which attracts the north pole of the compass needle will be the *south pole.*

EXERCISE 10 (A)

1. What is a lodestone ?
2. What is a natural magnet ? State *two* limitations of a natural magnet.
3. What is an artificial magnet ? State *two* reasons why do we need the artificial magnets.
4. How will you test whether a given rod is made of iron or copper ?

   [**Hint :** Iron rod gets magnetised when placed near a bar magnet by magnetic induction, while copper rod does not get magnetised]
5. You are provided with *two* similar bars, one is a magnet and the other is a soft iron bar. How will you distinguish between them without the use of any other magnet or bar ?

   [**Hint :** A magnet when suspended freely will rest only in the north-south direction, but the soft iron bar will rest in any direction]

6. Fill in the blanks to complete the sentences :
   (a) The two ends of a magnet are called ....
   (b) Unlike poles of a magnet .... each other.
   (c) Like poles of a magnet .... each other.
   (d) A freely suspended magnet rests in the geographic .... direction.

   Ans. (a) poles, (b) attract, (c) repel, (d) north-south

7. A small magnet is suspended by a silk thread from a rigid support such that the magnet can freely swing. How will it rest ? Draw a diagram to show it.
   Ans. It will rest in the geographic north-south direction with north pole towards the geographic north, making some angle with the horizontal as shown in Fig. 10.1.
8. Explain the meaning of the term induced magnetism.
9. Explain what do you understand by magnetic induction. What role does it play in attraction of a piece of iron by a magnet ?
10. Explain the mechanism of attraction of iron nails by a magnet when brought near them.
11. Explain the following :
    (a) When two pins are hung by their heads from the same pole of a magnet, their pointed ends move apart.
    (b) Several soft iron pins can cling, one below the other, from the pole of a magnet.
    (c) The north end of a freely suspended magnetic needle gets attracted towards a piece of soft iron placed a little distance away from the needle.
12. A small iron bar is kept near the north pole of a bar magnet. How does the iron bar acquire magnetism ? Draw a diagram to show the polarity on the iron bar. What will happen if the magnet is removed ?
13. 'Induced magnetism is temporary'. Comment on this statement.
14. 'Induction precedes the attraction'. Explain the statement.
15. What do you understand by the term magnetic field lines ?
16. State *four* properties of the magnetic field lines.
17. Explain why iron filings which are sprinkled on a sheet of cardboard over a bar magnet, take up a definite pattern when cardboard is slightly tapped.
18. Explain the method of plotting the magnetic field lines by using a small compass needle.
19. Can *two* magnetic field lines intersect each other ? Give reason to your answer.
20. In Fig. 10.12, draw at least *two* magnetic field lines between the two magnets.

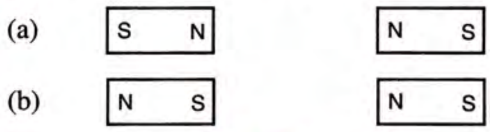


Fig. 10.12

21. State *two* evidences of the existence of earth's magnetic field.
22. Sketch *four* magnetic field lines as obtained in a limited space on a horizontal plane in the earth's magnetic field alone.
23. (a) Draw the pattern of magnetic field lines near a bar magnet placed with its north pole pointing towards the geographic north. Indicate the position of neutral points by marking ×.
    (b) State whether the magnetic field lines in part (a) represent a uniform magnetic field or non-uniform magnetic field ?
24. Fig. 10.13 shows a bar magnet placed on the table top with its north pole pointing towards south. The arrow shows the north-south direction. There are no other magnets or magnetic materials nearby.

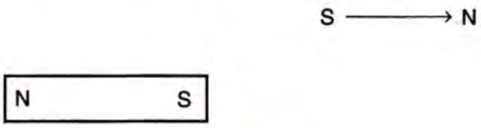


Fig. 10.13

    (a) Insert *two* magnetic field lines on either side of the magnet using arrow head to show the direction of each field line.
    (b) Indicate by crosses, the likely positions of the neutral points.
    (c) What is the magnitude of the magnetic field at each neutral point ? Give a reason for your answer.
25. What conclusion is drawn regarding the magnetic field at a point if a compass needle at that point rests in any direction ? Give reason for your answer.
    Ans. Magnetic field is zero. **Reason :** The earth's magnetic field at that point is neutralised by the magnetic field of some other magnetised material.

26. What is a neutral point ? How is the position of neutral point located with the use of a compass needle ?

27. State the positions of neutral points when a magnet is placed with its axis in the magnetic meridian and with its north pole (i) pointing towards the geographic north, (ii) pointing towards the geographic south.

Ans. (i) in east-west direction
(ii) in north-south direction.

28. Complete the following sentences :
(a) If the field lines in a magnetic field are parallel and equidistant, the magnetic field is ....
(b) At a neutral point, the resultant magnetic field is ....
(c) The neutral points of a bar magnet kept with its north pole pointing towards geographic north are located ....

Ans. (a) uniform, (b) zero, (c) on either side of the magnet in east and west.

Multiple choice type :

1. Two like magnetic poles :
(a) repel each other
(b) attract each other
(c) first attract each other, then repel
(d) neither attract nor repel.

Ans. (a) repel each other

2. In a uniform magnetic field, the field lines are :
(a) curved
(b) parallel and equidistant straight lines
(c) parallel, but non-equispaced straight lines
(d) nothing can be said.

Ans. (b) parallel and equidistant straight lines

(B) ELECTROMAGNET AND ITS USES

10.9 ELECTROMAGNET

An electromagnet is a temporary strong magnet made from a piece of soft iron when current flows in the coil wound around it. It is an artificial magnet.

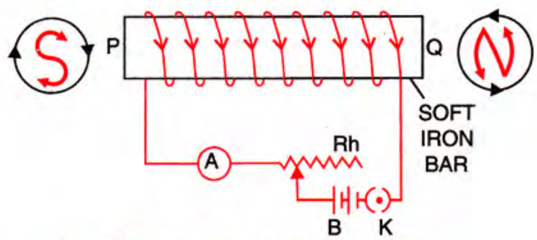


Fig. 10.14 I-shaped electromagnet

An electromagnet can be made in any shape, but usually the following *two* shapes of electromagnet are in use :

(a) I–shape (or bar) magnet, and

(b) U-shape (or horse-shoe) magnet.

(a) Construction of the I-shaped (or bar) electromagnet

To construct an I-shaped electromagnet, a thin insulated copper wire is wound in form of a solenoid around a straight soft iron bar *PQ*. The ends of the wire are connected to a battery *B* through an ammeter *A*, a rheostat *Rh* and a key *K* as shown in Fig 10.14.

When current is passed through the winding of solenoid by closing the key *K*, the end *P* of the bar becomes the *south pole* (*S*) since current at this face is clockwise, while the end *Q* at which the current is anticlockwise, becomes the *north pole* (*N*). Thus the bar becomes a magnet. The bar shows the magnetic properties only when an electric current flows through the solenoid and it loses the magnetic properties as soon as the current is switched off (since soft iron has a low retentivity), thus it is a temporary magnet. Such arrangement is commonly used in a relay.*

(b) Construction of the U-shaped (or horse-shoe) electromagnet

To construct a horse-shoe electromagnet, a thin insulated copper wire is spirally wound on the arms of a U-shaped soft iron core, such that the winding on the two arms as seen from the ends, is in *opposite sense*. In Fig. 10.15, winding on the arm *P* starts from the front and it is in the clockwise direction (when viewed from the bottom). On reaching the upper end of the arm *P*, winding starts from the back at the top of the arm *Q* and it is in anticlockwise direction.

* A relay is a switching device.

The ends of the wire are connected to a battery through an ammeter, rheostat and a key.

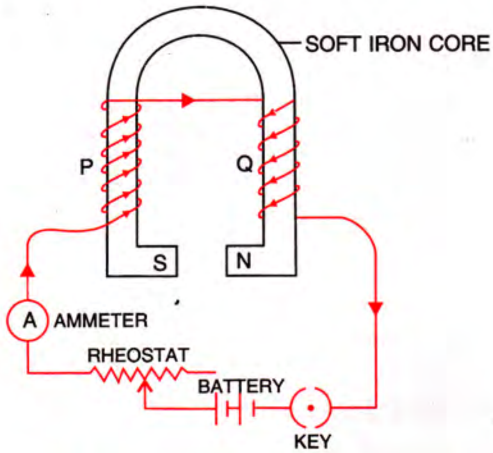


Fig. 10.15 Horse-shoe electro-magnet

When current is passed through the winding by closing the key, the end of the arm P becomes the *south pole S* (current at this face is clockwise) and the end of the arm Q becomes the *north pole N* (current at this face is anti-clockwise). Thus we get a very strong magnetic field in the gap between the two poles. The magnetic field in the gap vanishes as soon as the current in the circuit is switched off. Thus it is a temporary magnet. Such magnets are used in d.c. motor, a.c. generator, etc.

Note : For sending current in the coil, the source must be the d.c. source (*i.e.*, battery). With an a.c. source of frequency 50 Hz, although the soft iron core gets magnetised as long the current is passed, but its polarity magnetics as long to current is passed, but its polarity at the ends changes 50 times in each second.

Ways of increasing the magnetic field of an electromagnet

The magnetic field of an electromagnet (I or U-shaped) can be increased by the following *two* ways :

(i) by increasing the number of turns of winding in the solenoid, and

(ii) by increasing the current through the solenoid.

10.10 PERMANENT MAGNET

A permanent magnet is a naturally occuring magnet. Since it is not strong enough and of required shape for many purposes, so a strong permanent magnet is made like an electromagnet using steel instead of soft iron. A coil of insulated copper wire is wound around the steel piece and then current is passed in the coil. Once magnetised, it does not lose its magnetism easily (since steel has more retentivity than soft iron) so it becomes a permanent magnet. The permanent magnets are used in electric meters (*e.g.*, galvanometer, ammeter, voltmeter) and in magnetic compass, etc.

10.11 COMPARISON OF AN ELECTRO-MAGNET WITH A PERMANENT MAGNET

Electromagnet	Permanent magnet
1. It is made of soft iron.	1. It is made of steel.
2. It produces the magnetic field so long as current flows in its coil. *i.e.*, it produces the temporary magnetic field.	2. It produces a permanent magnetic field.
3. The magnetic field strength can be changed.	3. The magnetic field strength cannot be changed.
4. The magnetic field of an electromagnet can be very strong.	4. The magnetic field of a permanent magnet is not so strong.
5. The polarity of an electromagnet can be reversed.	5. The polarity of a permanent magnet can not be reversed.
6. It can easily be demagnetised by switching off the current.	6. It can not be easily demagnetised.

10.12 ADVANTAGES OF AN ELECTRO-MAGNET OVER A PERMANENT MAGNET

An electromagnet has the following advantages over a permanent magnet :

(i) An electromagnet can produce a strong magnetic field.

(ii) The strength of the magnetic field of an electromagnet can easily be changed by changing the current (or the number of turns) in its solenoid.

(iii) The polarity of the electromagnet can be reversed by reversing the direction of current in its solenoid.

10.13 USES OF ELECTROMAGNETS

Electromagnets are mainly used for the following purposes :

(i) For lifting and transporting heavy iron scrap, girders, plates, etc. particularly when it is not convenient to take the help of human labour. Electromagnets are used to lift as much as 20,000 kg of iron in a single lift. To unload the iron objects at the desired place, the current in the electromagnet is switched off so that the iron objects get detached.

(ii) For loading the furnaces with iron.

(iii) For separating the iron pieces from debris and ores, where iron exists as impurities (e.g., for separating iron from the crushed copper ore in copper mines).

(iv) For removing pieces of iron from wounds.

(v) In scientific research, to study the magnetic properties of a substance in a magnetic field.

(vi) In several electrical devices such as electric bell, telegraph, electric tram, electric motor, relay, microphone, loud speaker, etc.

Use of electromagnet in an electric bell

An electric bell is one of the most commonly used application of an electromagnet.

Construction and wiring : An electric bell is shown in Fig. 10.16.

The main parts of the bell are :

(i) a horse-shoe electromagnet *M*, having a soft iron core,

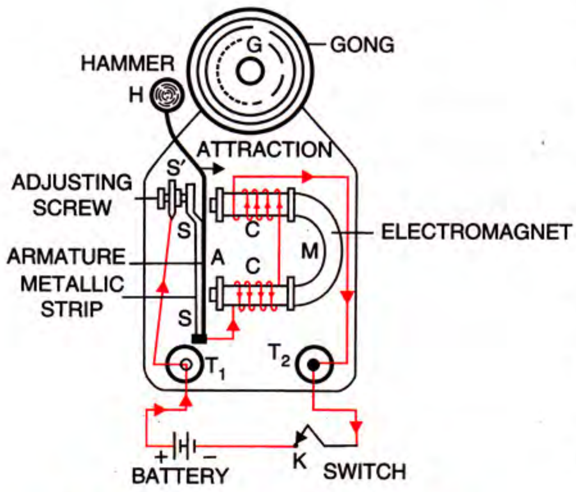


Fig. 10.16 Electric bell and its wiring

(ii) a soft iron armature *A*,

(iii) a hammer *H*,

(iv) a gong *G*,

(v) a metallic spring strip *SS*,

(vi) an adjusting screw *S′*,

(vii) a switch (or bell-push) *K*, and

(viii) a battery.

The armature *A* is fixed to the spring strip *SS*. The hammer *H* is attached at the upper end of the armature *A*. When the switch *K* is not pressed, the strip *SS* makes contact with the adjusting screw *S′* and there is a gap between the armature *A* and the poles of the electromagnet.

The coil *CC* is wound on the two arms of the electromagnet in the *opposite direction* as shown in Fig. 10.16. One end of the coil is connected to the terminal T_1 through the strip *SS* and the screw *S′*, while the other end is connected to the terminal T_2. A battery is provided in series with the switch *K* across the terminals T_1 and T_2.

Working and function of each part : When the electric circuit is closed by pressing the switch *K*, the current flows through the coil *CC* and the core of the electromagnet gets magnetised and therefore it attracts the armature *A* as shown by an arrow in Fig. 10.16. Due to movement of the armature *A*, the hammer *H* strikes the gong *G* and the bell rings.

At the moment, when the armature *A*, due to magnetic attraction, moves towards the electromagnet, the connection between the strip *SS* and the screw *S′* breaks due to which the flow of current in the coil stops. Consequently, the electromagnet loses magnetism (*i.e.*, it gets demagnetised) and the armature *A* flies back to its original position due to the spring effect of the strip *SS*. Now the armature *A* again touches the screw *S′*, resulting in the flow of current in the coil. The electromagnet regains its magnetism and the armature *A* is again attracted, so the hammer *H* again strikes the gong *G*. This process continues.

This process of make and break of the circuit goes on and the hammer strikes the gong repeatedly so the bell rings as long as the switch *K* is kept pressed.

Note : If an a.c. source is used in place of battery, the core of electromagnet will get magnetised, but the polarity at its ends will change. Since attraction of armature does not depend on the polarity of electromagnet, so the bell will still ring on pressing the switch *K*.

EXAMPLE

1. Draw a labelled diagram to make an electromagnet from a soft iron bar AB. Mark the polarity at its ends. What precaution would you observe ?

The labelled diagram is shown in Fig. 10.17. The polarity at the **end *A*** where the current is clockwise, is **south (*S*)**, while at the **end *B*** where the current is anticlockwise, is **north (*N*)**.

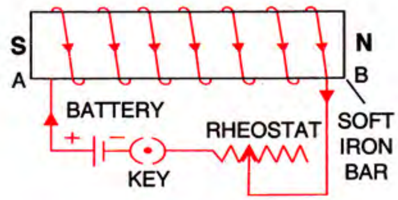


Fig. 10.17

EXERCISE 10 (B)

1. What is an electromagnet ?
2. Name the material used for preparing an electromagnet.
3. How is an electromagnet made ? Name *two* factors on which the strength of magnetic field of the electromagnet depends.
4. You are required to make an electromagnet from a soft iron bar by using a cell, an insulated coil of copper wire and a switch. (a) Draw a circuit diagram to represent the process. (b) Label the poles of the electromagnet.
5. Fig. 10.18 shows a coil wound around a soft iron bar *XY*. (a) State the polarity at the ends *X* and *Y* as the switch is pressed. (b) Suggest *one* way of increasing the strength of electromagnet so formed.

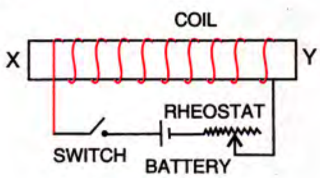


Fig. 10.18

Ans. (a) *X*-north pole, *Y*-south pole.
(b) By increasing the current in the coil.

6. A coil of insulated copper wire is wound around a piece of soft iron and current is passed in the coil from a battery. What name is given to the device so obtained ? Give *one* use of the device mentioned by you.
Ans. Electromagnet, electric relay.
7. Show with the aid of a diagram how a wire is wound on a U-shaped piece of soft iron in order to make it an electromagnet. Complete the circuit diagram and label the poles of the electromagnet.
8. State *two* ways through which the strength of an electromagnet can be increased.
9. Name *one* device that uses an electromagnet.
Ans. Electric bell.
10. State *two* advantages of an electromagnet over a permanent magnet.
11. State *two* differences between an electromagnet and a permanent magnet.
12. Why is soft iron used as the core of the electromagnet in an electric bell ?
13. How is the working of an electric bell affected, if alternating current be used instead of direct current ?
14. Name the material used for making the armature of an electric bell. Give a reason for your answer.

Multiple Choice Type

1. Electromangets are made up of :
(a) steel (b) copper
(c) soft iron (d) aluminium
Ans. (c) soft iron
2. The strength of the electromegnet can be increased by
(a) reversing the directions of current
(b) using alternating current of hight frequency
(c) increasing the current in the coil
(d) decreasing the number of turns of coil.
Ans. (c) increasing the current in the coil